2002-06

The effect of sound spatialization on responses to overlapping messages

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http://hdl.handle.net/10945/5951

NAVAL POSTGRADUATE SCHOOL
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THESIS

THE EFFECT OF SOUND SPATIALIZATION ON RESPONSES TO OVERLAPPING MESSAGES

by

James R. Campbell

June 2002

Thesis Advisor:	Russell D. Shilling
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This thesis done in cooperation with the MOVES Institute.

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REPORT DOCUMENTATION PAGE			*Form Approved OMB No. 0704-0188*
Public reporting burden for this collection of information is estimated to average 1 hour per response, including the time for reviewing instruction, searching existing data sources, gathering and maintaining the data needed, and completing and reviewing the collection of information. Send comments regarding this burden estimate or any other aspect of this collection of information, including suggestions for reducing this burden, to Washington headquarters Services, Directorate for Information Operations and Reports, 1215 Jefferson Davis Highway, Suite 1204, Arlington, VA 22202-4302, and to the Office of Management and Budget, Paperwork Reduction Project (0704-0188) Washington DC 20503.			
1. AGENCY USE ONLY *(Leave blank)*	**2. REPORT DATE** June 2002	**3. REPORT TYPE AND DATES COVERED** Master's Thesis	
4. TITLE AND SUBTITLE: Title (Mix case letters) The Effect of Sound Spatialization on Responses to Overlapping Messages			**5. FUNDING NUMBERS**
6. AUTHOR(S) James R. Campbell			
7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES) Naval Postgraduate School Monterey, CA 93943-5000			**8. PERFORMING ORGANIZATION REPORT NUMBER**
9. SPONSORING /MONITORING AGENCY NAME(S) AND ADDRESS(ES) N/A			**10. SPONSORING/MONITORING AGENCY REPORT NUMBER**
11. SUPPLEMENTARY NOTES The views expressed in this thesis are those of the author and do not reflect the official policy or position of the Department of Defense or the U.S. Government.			
12a. DISTRIBUTION / AVAILABILITY STATEMENT Approved for public release; distribution is unlimited			**12b. DISTRIBUTION CODE** None

13. ABSTRACT *(maximum 200 words)*

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Results indicated that participants accurately identified 43% of the messages in the spatialized condition, but only 17% of the messages in the non-spatialized condition. Chi-squared tests indicated a dependent relationship between accuracy and spatialization under a variety of conditions. The logit regression model confirmed these conclusions and indicated that the chance of a completely correct response was improved by approximately 30% with the use of spatialization.

14. SUBJECT TERMS Communications, Auditory Displays, Sound Localization, Spatialization, Overlapping Messages, Spatial Audio, Logit Regression, Cochran's Test			**15. NUMBER OF PAGES** 137
			16. PRICE CODE
17. SECURITY CLASSIFICATION OF REPORT Unclassified	**18. SECURITY CLASSIFICATION OF THIS PAGE** Unclassified	**19. SECURITY CLASSIFICATION OF ABSTRACT** Unclassified	**20. LIMITATION OF ABSTRACT** UL

NSN 7540-01-280-5500 Standard Form 298 (Rev. 2-89)
Prescribed by ANSI Std. 239-18

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THE EFFECT OF SOUND SPATIALIZATION ON RESPONSES TO OVERLAPPING MESSAGES

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MASTER OF SCIENCE IN OPERATIONS RESEARCH

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ACKNOWLEDGMENTS

I would like to thank LCDR Russ Shilling for his invaluable assistance with the completion of this thesis. His expertise in auditory perception was crucial for designing experimental procedures and interpreting data from human subjects.

I would also like to thank Professor Robert Read for his generous contributions to my data analysis efforts. His knowledge of S-plus saved countless hours of work, particularly the implementations of Cochran's Test and Time Series Plots.

I would also like to extend my gratitude to all of the faculty members and fellow students who volunteered to participate in the pilot study and final experiment.

Finally, I would like to thank my wife for all of her support during this long process. It certainly would not have been possible without her love and patience.

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EXECUTIVE SUMMARY

The purpose of this research was to determine if a spatialized headphone display would increase speech comprehension when listening to multiple simultaneously presented messages. The design was intended to simulate a multi-channel radio communication task. There are numerous military applications that could potentially be improved by this type of display. Possible settings range from aviation communications to shipboard combat information centers.

Prior research has demonstrated the benefit of spatially separating competing message sources, but these experiments have generally been limited to two audio sources and used multiple loudspeakers instead of spatialized audio over headphones. One of the objectives of this research was to determine if these results could be extended to a scenario that used up to four overlapping messages with a headphone display.

Two experiments were conducted in the Advanced Auditory Displays Laboratory at the Naval Postgraduate School. These studies utilized 36 participants. The first experiment was a pilot study, which was designed to identify the factors that contributed to changes in response accuracy. The conclusion of this effort was a decision to use a combination of chi-squared tests for independence and multivariate logit regression to examine the influence of several factors, with a focus on the effect of spatialization

Results from the final experiment indicated that 17% of participant responses were completely correct without spatialization versus 43% with spatialization. The chi-squared tests indicated a dependent relationship between accuracy and spatialization under a variety of conditions. The logit regression model confirmed these conclusions and indicated that the chance of a completely correct response was improved by roughly 30% with the use of spatialization.

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I. INTRODUCTION

A. BACKGROUND

Military operational environments routinely require personnel to attend to multiple sources of information. Often this information is delivered through headphones or loudspeakers. This is most frequently the case when there is a need for real-time speech communications. In the Navy, there are a variety of functions that specifically require the use of headphone or earpiece communications. Some examples include pilots, air traffic controllers, flight deck personnel, tactical action officers, and fire control teams. Often, there is an additional requirement to monitor multiple channels or networks at one time. For these types of tasks, difficulties arise when there is a need to attend to two or more messages simultaneously.

Switching between networks raises the possibility that information could be lost in a busy, overloaded environment. Adding multiple message sources to each channel reduces the number of switches that are required, but it presents a new obstacle in the form of message intelligibility. One solution to this problem is to separate the messages spatially, so that they are not perceptually localized at the same point in space. In the most basic configuration, one message can be sent to the left ear, while another is sent to the right (diotic presentation). The result may not meet the ideal of listening to a single speaker at a time, but is preferable to messages that are not spatially separated (monotic presentation). The limitation to this technique is obvious. Adding more than two messages results in the same overlapping babble that existed before the separation.

Advances in modern audio technology offer a potential solution to this dilemma. It is now possible to synthesize spatial auditory cues over headphones. This means that a three dimensional listening environment can be generated without the use of prohibitively large and expensive loudspeaker configurations. The significance of this capability is that a listener could simultaneously perceive more than two messages that are spatially separated. The headphone listener would perceive each sound source as if it were located

in a different point in space, a situation that is comparable to a person who is trying to follow a single conversation in a crowded room.

The question, however, is whether spatial audio presented over headphones is really analogous to a room full of people. Clearly there are differences. One such difference is the lack of visual cues. Facial expressions, especially lip and mouth movement, are good examples of visual stimuli that help a listener to understand speech. Despite the differences, there are anecdotal reasons to believe that the separation of sounds offers an advantage over a cacophony that seems to originate from one location.

Research dating back to the mid 1940s and 50s provides empirical evidence that there are advantages to using binaural displays that spatially separate messages between the ears. These types of systems are already in use, but the headphone component is always limited to two messages, one for each ear. More recent studies have gone further to demonstrate the benefits of sophisticated headphone displays, but they have also been limited to the study of either two competing messages, or a message and noise.[1] This is unfortunate for two reasons. First, they do not fully test the advantage of a 3-D auditory environment because they maintain the two-source limitation. The angle of separation in the older binaural displays may not be optimal for maximizing word intelligibility, but a spatial auditory environment with only two sound sources does not significantly reduce the burden of managing multiple communication networks. Finally, these experiments beg the question of whether the benefits of spatial audio persist when more sound sources are added?

B. RESEARCH OBJECTIVE

The primary purpose of this research is to examine the benefit of spatial auditory displays for speech communications. More specifically, it focuses on whether spatialization provides an advantage when a listener is forced to attend to more than one message at a time. This question is explored in two ways. First, a review of previous experiments is presented as general background and to establish that some researchers

[1] Details are included in Chapter 2, sections B.2 and B.3.

have found an advantage to separating two competing messages. Second, a description of two new experiments is provided along with an analysis of data collected in the Advanced Auditory Displays Laboratory at the Naval Postgraduate School. These studies were significant because they made use of trials with two, three, and four overlapping messages.

A secondary objective of this research is to lay the groundwork for future study. The protocols and procedures used in the experimental portion may be useful for related thesis work in verbal communications. In addition, the analysis of results could potentially lead to new hypotheses and testing.

Ultimately, the objective of all research in this area is to improve the productivity and safety of the military working environment by using new technology to improve auditory displays.

C. SCOPE AND LIMITATIONS

Much of this research, particularly the experimental portion, is intended to apply to generic verbal communications. The objective is to simulate a scenario that is relevant to the armed forces, but the subject matter is not limited to a specific military function or application. For example, participants were asked to listen for a call sign and answer a question regarding message content. The messages were framed to give the general impression of a military setting, but the actual function being performed was ambiguous. The participants were never told that they were flying a helicopter, leading an infantry company, or manning a station on a ship.

This broadness of scope is beneficial for two reasons. First, it allows for a simpler experiment. A more detailed military scenario might present a convincing simulation of a particular task, but it would also be more difficult to standardize the trials. This is particularly important for drawing statistical inferences from the results of the experiment.

The second benefit of using a broader scope is that the results are easy to generalize. A study that focused on the communications environment of a single community might produce results, which seemed more relevant to one group, but it would also run the risk of appearing inapplicable to others.

Using a laboratory and generic scenarios provides analytical benefits, but also creates significant limitations. Foremost is the hypothetical effect that the lack of context could have on performance. Participants might respond differently when placed under the demands and stresses of a real working environment. There are no external threats in the laboratory setting and there is no requirement to perform a vigilance task, such as flying or driving.

Another limitation of this research is that it does not explore the technical requirements of implementing spatial auditory displays in a military environment. This is partially a function of conducting research in a laboratory setting. The type of equipment used for this research might work in some environments, like shore based communications, but clearly would not work in others. The more significant issue, however, is the need to limit the scope of this research. Similarly, a full cost-benefit analysis would be both premature and outside the domain of the research objectives.

Aside from the setting, other limitations exist. From the technical perspective, individualized Head Related Transfer Functions (HRTFs) were not used in this research. Measuring certain outer ear, or pinnae, characteristics and using them as parameters in the synthesis of spatial audio can improve the ability of a listener to localize a sound source.

The alternative was to use generalized or “generic” HRTFs. This limitation is not significant for two reasons. First, localization accuracy was not the main dependent variable in the experiment. The ability to correctly identify the position of a source could be much more important in a different setting, such as the sonification of search and detection processes. In communications however, localization is only important to the extent that it improves intelligibility. Second, the cost of measuring and utilizing individual HRTFs in a field setting is potentially prohibitive. One difficulty is that the measurement process would need to be conducted for all personnel that intended to use a

particular application. It would also have to be repeated whenever turnover occurred. Additionally, a relatively quiet room is useful for measuring HRTFs. Noise and space limitations are obstacles that would exist in many field settings. Finally, a process would need to be established in order to insure that the correct HRTFs were loaded whenever an application was used.

If a performance increase exists without these complications, it is important to use that increase as a baseline for future study. Only then can a theoretical improvement be compared to the extra cost in time, money, and system complexity.

D. ORGANIZATION

The thesis is organized into five chapters. The introductory chapter explains the motivation for pursuing this topic and provides a very general background on the use of spatial auditory displays. The second chapter provides focus for the research question in two ways. First, it presents an overview of the principles of spatial auditory perception. Second, it summarizes a comprehensive literature review by describing the results of several experiments that have dealt with either responses to multiple messages or message delivery in a spatial environment. The third chapter describes the methodology and analysis of a pilot study, while the fourth chapter uses the same format to present results from a larger experiment. Finally, chapter five contains conclusions and recommendations.

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II. PROBLEM FOCUS

A. SPATIAL AUDITORY ENVIRONMENTS

1. Basic Elements of Auditory Perception

Sound is created by vibrations from a source that are transmitted as a pressure wave with alternating peaks and valleys. Theses waves can travel through a variety of media, but are generally described as a stimulus transmitted to the ear through the atmosphere. (Sanders and McCormick, 1993, p. 161) Simple sounds can be represented as a sinusoidal function with time on the horizontal axis and intensity on the vertical.

The two primary attributes of sound are intensity and frequency. Intensity corresponds to the amplitude of the sine wave. The distance from the horizontal axis to the peak of a wave is the difference between normal air pressure and the maximum condensation caused by the sound wave. Intensity is normally measured in decibels, which are relative units to some reference level on a logarithmic scale (Shilling and Shinn-Cunningham, 2002, p. 2.1.2).

Frequency (λ), corresponds to the wavelength, or distance between adjacent extrema, of the sine function. Hertz (hz), or cycles per second, are used to describe the frequency of a sound. Generally, the human ear can detect sounds in the 20-20,000 hz range, but there is significant variation in sensitivity to individual frequencies. It is also important to note that there are large differences between individuals in their relative abilities to detect a specific frequency (Sanders and McCormick, 1993, p. 161).

The mechanical and cognitive processes of human hearing are complex. The full details are beyond the scope of this research, but a basic overview is useful for understanding some of the variables that affect spatial hearing. First sound is transformed by the pinnae, or visible portion of the outer ear. More specifically, the size and shape of a pinna physically affect the collection of sound energy. This stage is also influenced by parts of the body that are close to the ears, such as the head and shoulders. Next, acoustical energy is conveyed through the meatus, or ear canal, to the tympanic

membrane. This membrane, also called the eardrum, works in conjunction with three small bones, called ossicles, or hammer-anvil-stirrup, to convert acoustical energy to mechanical energy. This energy is transferred to the inner ear, or cochlea, via the oval window and continues as fluid pressure. This pressure causes dependent vibration patterns of the basilar membrane, which cause numerous fibers protruding from auditory hair cells to bend. This process activates electrical action potential in auditory neurons and combines at higher levels with information from the opposite ear to produce aural perception. (Bergault, 2000, p. 7)

The last stage in this account is clearly crucial to the way in which humans use auditory stimuli. Sounds are not perceived in terms of waves or pressure changes. At the cognitive level, frequency and intensity are perceived as loudness, pitch and timbre. For example, listeners are generally sensitive to intensity on a logarithmic scale. As a result, the repeated doubling of a sound's intensity level is normally perceived as a series of volume increases that are equal in magnitude.

Frequency is more complex because the general example of the sine wave only applies to pure tones. In practice, most sounds are complex combinations of frequencies. The simplest case, called harmonics consists of a pure tone at a particular frequency that is combined with other tones whose frequencies are multiples of each other. Even harmonics are relatively uncommon among complex sounds. Some aperiodic sounds do not have a discernible pitch and are characterized as noise. The pitch of other complex sounds usually depends on the average period of the cyclical variations of the stimulus. (Shilling and Shinn-Cunningham, 2002, p. 3.4)

Timbre is even more difficult to define. It includes the qualities of sounds that allow a listener to distinguish between two sounds of the same pitch and loudness. This also raises the issue that perceptual attributes of sound, such as loudness and pitch, are not exact correlates of frequency and intensity. Interactions exist in both cases. Perceived loudness, for instance, is not a simple function of intensity because there are instances where frequency has a significant effect. Similarly, intensity can affect perceptions of pitch. This is particularly true with complex sounds.

Another form of interaction involves the presence of multiple sound sources in the same environment. In this case, one sound can have a masking effect on another sound. Masking is normally defined as a change in the minimum intensity that is needed to make a sound detectable. The change in this threshold can be measured and attributed to a masking effect. The extent of this phenomenon depends on frequency and intensity. In general, low intensity masking (20 to 40 dB) is constrained to a narrow band of frequencies around those of the masking sound, while higher intensities widen the range of frequencies that are affected. (Sanders and McCormick, 1993, p.168)

Speech communications, the focus of this study, provide a practical example for the masking concept. Since most speech information is conveyed by sounds that are between 200 and 5000 Hz, it is particularly important to reduce or eliminate the intensity of noise in this range. Otherwise, word intelligibility and message comprehension can be compromised. Obviously, the presence of multiple speech sounds increases the chance of overlapping frequency ranges. This is one of the reasons why spatial separation can play a vital role in auditory perception. It cannot eliminate the detrimental effects of masking or conflicting message content, but it can potentially moderate them.

2. Spatial Hearing

Localizing sound in space is a perceptual process that occurs when the stimulus arriving in one ear is compared to that of the opposite ear. The two principal cues in spatial auditory perception are interaural time differences (ITD) and interaural intensity differences (IID).

ITDs are the primary spatial cue for sounds with lower frequencies. For sounds under 1.5 kHz, the half period of a sound wave is normally larger than the size of the head, so the brain can accurately detect the phase of these waves and the ITD cue can function. If the intensity of a sound wave varies, then the amplitude modulation creates an envelope at a frequency much lower than the carrier frequency. Under these conditions, the ITD can continue to operate at higher frequencies. (Bergault, 2000, p.33)

At higher frequencies, particularly above 2 kHz, sound waves are generally smaller than the head. The resultant signal diffraction, or head shadowing, causes an intensity difference between the ear that is closer to the sound source and the one that is on the opposite side of the head (IID). For sounds that are closer than one meter, extra large IID cues can occur from the relative differences in the distance of a source between one ear and the other. These cues are important, even for low frequency sounds. In addition, a torso shadowing effect can cause an IID for nearby objects that increases the accuracy of elevation localization. (Shilling and Shinn-Cunningham, 2002, p. 3.6.1)

The combination of IID and ITD cues provide accurate localization effects in a variety of circumstances, but the resolution of this auditory process is not as consistent as comparable visual processes. First, there are multiple source locations that produce the same ITD and IID cues. At a distance of more than a meter from the head, these points form a cone of confusion where the location of a sound can appear ambiguous. Inside of one meter, there are corresponding tori of confusion centered on the interaural axis that also prevent the determination of a sound source's location. (Shilling and Shinn-Cunningham, 2002, p. 3.6.1) Second, midrange frequencies between 1500 and 3000 Hz can be difficult to localize because they do not produce an adequate difference in phase or intensity. This creates a front-back confusion, which makes it easy for a listener to reverse the direction a sound is coming from.

There are several other factors that effect localization. Head movement, for instance, is the primary means of resolving front-back confusion. Consider a polar coordinate system where the zero degree mark is located directly to the right of a listener. A stationary sound source at thirty degrees could be mistaken for a sound located at 150 degrees. Turning the head back and forth can resolve this uncertainty. If the sound becomes increasingly centered as the head moves to the right, then it confirms that the sound is to the right and forward. In more precise terms, the centering effect is a decrease in the interaural differences. If, on the other hand, the differences increased as the head moved to the right, then the sound would have to be to the left and rear (Bergault, 2000, p. 39).

Finally, the role of higher-level cognitive processes cannot be ignored. Past experience and reasoning often override judgments that would be formed solely from physical stimuli. In particular, expectation can often dictate both visual and auditory spatial perception. Durand Bergault provides the account of a famous 3-D sound system demonstration in which the listener heard the sound of scissors cutting hair near the ear. The sensation seemed so real that some listeners reached for their heads to make sure that there were no scissors. Similarly, the sounds of a cigarette being lit and a person drinking a glass of water produced a strong sense of sounds originating from an area in front of the mouth. As Dr. Bergault pointed out, these are very difficult perceptions to produce with interaural cues because of the potential for reversals in this area. The sound system designer argued that this was proof of the quality of their system, but Dr. Bergault maintained that our knowledge of similar circumstances shows that a listener's experiences with these activities would not have allowed them to hear the sound from anywhere else. He went further to contend that an un-localized monaural display, played into both ears at the same decibel level would likely cause an identical spatial perception. (Bergault, 2000, p. 29)

3. Spatial Auditory Displays

There are two main methods of re-creating three-dimensional auditory environments, loudspeakers and headphones. A distinction should be made between 3-D and surround sound, particularly in situations where speaker configurations are used. The primary purpose of stereo surround sound is to enhance music by making it sound more spacious. This effect can be accomplished by adding a single speaker that is out of phase with the normal left and right stereo speakers. Theater surround sound systems are slightly more complex because they utilize up to four separate channels for sounds. Most soundtracks utilize a center channel for dialogue, regardless of where the speaker is located in relation to the audience. Music and Foley effects, like footsteps, are usually played on the left and right side channels. The last channel connects to multiple rear speakers and is reserved for background environmental sounds that are meant to be diffused and envelop and audience. (Bergault, 2000, pp. 16-17)

3-D sound environments are more complex because sounds are represented as emanating from precise points in space. The limitations of loudspeakers should be obvious. Each position in a 360-degree sphere around a listener potentially requires a separate speaker to act as the sound source. Room characteristics, like reverberation, also become an issue. While some reverberation can add a sense of realism, it can also confuse localization. Special rooms, called anechoic chambers, eliminate this problem, but they are expensive and unrealistic for most practical applications.

More often than not, headphone systems present a cheaper and more effective method for creating three-dimensional sound environments. Intensity and timing differences between the left and right ear can be used to synthesize the perception of a sound source located in a specific position. Of course, the same problems that cause reversals and confusion in real listening environments also apply to artificial ones. In addition, there are new problems that need to be taken into account.

The major disadvantage of traditional headphone techniques is that sounds can appear to come from inside the head, even when interaural difference cues are utilized. Some argue that this is a natural consequence of bone conduction or pressure on the head, but there are several factors that have been found to improve this condition. The addition of head tracking devices can be used to mimic the change in interaural differences that occur when the head moves in relation to a stationary sound source. This technique carries two advantages. First, it can help increase the perception of externalization, a sense that the sound is originating from outside the head. Second, it can improve localization accuracy, particularly with the previously mentioned ability to resolve front-back ambiguity.

A second technique that can increase externalization and improve localization accuracy is the use of head related transfer functions (HRTFs). HRTFs are obtained by measuring the pressure put on the eardrum by sound pressure originating from a fixed point in space. This measurement, also known as a Head Related Impulse Response (HRIR), is repeated by moving the source to different points around the listener. The final product of this mapping, the HRTF, is the result of a Fourier transform of the HRIR data. HRTFs account for individual characteristics that can influence interaural

differences through signal disruption. These can include the size and shape of the pinnae, distance between the ears, aspects of the neck and shoulders, and even facial characteristics. Theoretically the use of HRTFs allows a listener to hear sounds more naturally. The alternative is to use measurements from a good localizer or to form some type of average HRTF.

B. PRIOR COMMUNICATIONS EXPERIMENTS

1. The Cocktail Party Problem

There is an immense amount of research literature associated with the general topic of spatial auditory perception. Rayleigh's *On our perception of sound direction* (1907) was published in Philosophica magazine nearly a century ago. Subsequent experimentation covered a wide variety of sub-topics, including the effect of spatial separation (binaural versus monaural hearing) on masking and detection thresholds.

The ability of a listener to hear one sound in the presence of a competing signal is marginally relevant to the topic of multiple message environments, but it is important to note that many of these experiments used simplified versions of real perceptual tasks. For example, research conducted by Ira Hirsh at Harvard University[2] in 1948 studied the effect of interaural phase on summation and inhibition. He referred to earlier research, which showed the advantageous threshold decrease associated with binaural displays. The problem with this group of studies from the 1930s and 40s is that they concentrated on target sounds that consisted of pure tones and masking sounds that were composed of noise (Hirsh, 1948, p.1). The relevance of this research is that it illustrates that there are issues associated with the perception of complex sounds, like speech, that can be ignored with a simplified experiment. The problem, of course, is that the results of such experiments are less significant if a researcher is primarily concerned with verbal communications.

[2] Dr. Hirsh's research was performed under contract between Harvard University and the Office of Naval Research.

In 1953, E. Colin Cherry, a researcher from the Imperial College of the University of London, published an article entitled *Some Experiments on the Recognition of Speech, with One and Two Ears*. His work was conducted at MIT under a Fulbright grant and was partially funded by the Army Signal Corps, the Air Materiel Command, and Office of Naval Research. He coined the phrase "Cocktail Party Problem" to describe a situation in which a listener attempts to follow one conversation in a room full of people who are talking in small groups.

Cherry listed five factors that he felt allowed a listener to discriminate between conflicting spoken messages. These included visual cues such as lip reading; differences in voice pitch, timbre, and speed; differences in accents; transition probabilities, which he used to describe differences in subject matter, voice dynamics and syntax; and lastly, the fact that voices come from different directions. (Cherry, 1953, p. 976) He controlled all variables except for sound direction and message content in order to test his theory that the location of sound played a major role in the filtering of multiple messages. He accomplished this by recording two messages, read by the same speaker, onto a single tape. The result, predictably, was nearly incoherent babble. He compared the ability of participants to comprehend message details from these un-separated messages to a different setup in which one message was played into each ear through headphones.

The results of this comparison showed a dramatic increase in performance with separated messages. Message comprehension and recall noticeably improved for the attended message. The results regarding the rejected message were equally interesting. Participants could recall no significant details of the message that they ignored. In fact, a subsequent test showed that a participant did not even recognize the fact that the rejected message was changed to German, albeit spoken by the same Englishman who read the target message. (Cherry, 1953, p. 978)

Subsequent experiments on the effect of spatial separation on multiple message intelligibility can be divided into two categories. The first category used two or more loudspeakers to create localized sound sources. The second group used headphones.

2. Multiple Message Experiments with Loudpseakers

In 1953 and 1954 a pair of experiments was conducted at the Human Factors Division of the U.S. Navy Electronics Laboratory in San Diego, California. J.C. Webster and P.O. Thompson sought to follow up Cherry's work with a study that required listeners to attend to both of two overlapping messages. They used air traffic control operators as participants and graded their verbal responses to simulated tower communications that utilized flight identification numbers in short, three word messages.

Two configurations were used to deliver messages. The first sent messages from one of six speakers to a single loudspeaker. Up to two messages could be displayed at once, with various degrees of overlap. The second configuration used six loudspeakers, one for each potential message source.

The results showed significant improvement in word and flight number identifications with the multiple speaker display. Furthermore, Webster and Thompson tested a message pull-down system that showed additional improvement when one of the messages could be redirected into either a seventh speaker or a single earphone (Thompson and Webster, 1953, p.399). One interpretation of this result is that the pull-down increased the intensity difference and spatial separation between the two messages. The idea that the angle of separation might influence performance was not explicitly studied in this experiment, but it was pursued a year later by Webster and two other colleagues at the Navy Electronics Laboratory.

Walter Spieth, James Curtis, and John Webster published *Responding to One of Two Simultaneous Messages* in 1954. Their experiment had three treatments for spatial separation. Each was meant to display messages from sources that were given the call signs of Able, Baker, and Charlie. The first treatment was a singe speaker that would play overlapping messages. The second was a three-speaker array with 10-20 degrees of separation between speakers and the third was a similar array with 90-180 degrees of separation. Like the earlier work of Thompson and Webster, Spieth et. al. also tested pull-down methods.

Each message contained several elements. The first was an identification of the message channel, Able, Baker, or Charlie. The second element was the intended recipient. One message would always be addressed to Oboe, the call sign for the participant. Another message would be addressed to one of nine one-syllable code names. Each message would also identify a speaker, separately from the channel identification. Finally, each message would contain a question about a visual display in front of the listener.

Participants were graded on the accuracy of their responses to the visual display questions. A variety of parameters affected accuracy, including the use of pull-downs and visual filters. Regardless, all cases showed a large improvement in accuracy when spatial separation was used and a small additional increase when the larger angle of separation was used. (Speith et. al., 1954, pp. 391-393)

The benefits of spatial separation raised a question of whether some angles were more beneficial than others. As an example, Thompson and Webster revisited this issue in 1963 and 1964 by examining the effect of talker listener angles on word intelligibility. Their first study was inconclusive (Thompson and Webster, 1963, p.323), but they found a benefit in turning a listener 15 to 75 degrees from a talker in their second experiment. The magnitude of the benefit was roughly equivalent to a change in distance of three and a half meters, but they were less comfortable with this result because there were discrepancies among researchers who were studying this question (Thompson and Webster, 1964, p. 44). Ultimately, the issue was of limited importance for topics involving electronic communications because there are many factors, like shadowing effects from bodies that are not a concern unless the talker and listener are in the same vicinity.

More recently, a series of experiments was conducted at the Wright-Patterson Air Force Base in the Armstrong Laboratory's Biocommunications facility. Specifically, a group of tests performed in 1994 by Richard McKinley and Mark Ericson tested the effects of a 3-D Auditory display in both a flight demonstration and in the Armstrong Laboratory. The laboratory portion of their experiment used a geodesic sphere, with 272 matched loudspeakers, which was placed in an anechoic chamber. They conducted

several studies including measures of localization performance and communication studies.

The communications experiment involved the transmission of one, two, and four messages against a background of pink noise. Messages contained a call sign, a color, and a number. Intelligibility was evaluated using a coordinate response measure (CRM). The results indicated an increase in the percent-correct CRM measure when spatial separation was used. The amount of the improvement varied, but the average was 25-28% higher than the diotic presentation. (McKinley and Ericson, 1995, p. 695)

McKinley and Ericson's communication experiment is significant because it provided a quantitative measure of performance in a spatial auditory environment with up to four competing message sources. The shortcoming is that the auditory display took place in an impractical setting. First, anechoic chambers are difficult and potentially expensive to construct. Second, while the geodesic sphere is more space efficient than the 24-speaker array that had been used previously, its performance might have been dependent on the room conditions.

Despite the importance of early experiments that utilized loudspeakers to create spatial audio displays, there are limited practical applications for these types of configurations. Headphone systems, on the other hand, have the potential to be applied to a wide variety of settings. They generally require less space and they limit some of the external concerns that have driven researchers to build complex acoustic environments. The space consideration by itself could be the deciding factor in many military applications. The display that McKinley and Ericson used for the flight demonstration portion of their research is a good example of a 3-D audio display that was integrated into a practical field application.

3. Multiple Message Experiments with Headphones

The flight demonstrations described by McKinley and Ericson were conducted as a joint effort by the Air Force and Navy with T-1 AV-8B Harrier VTOL aircraft. McDonnell aircraft integrated Armstrong Laboratory's 3-D audio system with the AV-

8B's mission computer. A modified Gentex HGU-53/P flight helmet included a Bose PRU-57 headset with military active noise reduction (ANR) capabilities. The headset system also included a head tracker that had been implemented for a previous study.

Four Navy and Marine Corps pilots participated in two sets of tests. The first set consisted of localization tests that were intended to measure the effectiveness of a 3-D audio cue in target identification and discrimination activities. The second set included the use of a 3-D audio display for communications, but the only performance measures reported were the subjective ratings of the pilots.

The communications tests were relevant to this research because they demonstrate the ability to implement 3-D audio headphone displays in a real military environment. Unfortunately, the data reported in this experiment was limited to anecdotal accounts provided by the participants. One pilot commented that he would not have been able to copy dual message traffic without the display. The other three pilots liked the system but "did not consider it a high priority" (McKinley and Ericson, 1995, p.696).

During the 1980's, researchers at the NASA-Ames Research Center were concerned with many of the same questions as their Air Force counterparts at the Armstrong Laboratory. Elizabeth Wenzel began the development of an auditory localization system, eventually dubbed the Convolvotron that was similar in basic functionality to the system that was used by McKinley and Ericson. Both centers were largely concerned with issues such as localization accuracy and modeling HRTFs, but there was also a peripheral concern with communications applications.

In 1993, Durand Bergault, a colleague of Dr. Wenzel's, conducted an experiment that measured the effect of a spatial auditory display on message intelligibility. His intention was to quantify the advantage of spatial separation in terms of threshold changes. In some ways, this concept was similar to experiments that had been performed in the 1940s with simple binaural separation. These experiments had played a pure tone in one ear (0 degrees) and noise in the other (180 degrees). The results had shown an advantageous shift in the detection threshold and were cited by Cherry when he published his findings in 1953.

The important difference between research done in the 1940s and the studies conducted fifty years later is that the more recent experiments moved beyond measuring signal detection to the intelligibility of complex sounds. Dr. Bergault utilized a vocabulary of 130 call signs that are typically used in NASA communications at the Kennedy Space Center.

During the experiment, call signs were played in one location while speech babble was played at another. Participants were prompted to type in the call signs that they heard. Each was four letters in length, mostly acronyms. The final results showed two things. First, spatial separation offered an advantage over a diotic presentation. Second, placing sound sources at 60 and 90 degrees appeared to offer an additional advantage over the simple binaural case, which uses 0 and 180 degrees. (Bergault, 1993, p.7)

Dr. Bergault's conclusion that a true 3-D auditory display is at least as good as a binaural display is significant. It has been obvious for some time that there is an advantage to separating sound sources, but if true spatialization does not offer an additional benefit, then there is no reason to add extra complexity to an auditory display. There is another important aspect to this question, specifically, whether it is feasible for a listener to attend to more than two messages at the same time? If it is possible, then the advantages of spatialization could be measured not just in the decibel change of an intelligibility threshold, but also in the increased ability to handle multiple channels of communication.

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III. PILOT STUDY

A. METHODOLOGY

1. Overview

Over the last seventy years, researchers have established the advantage of using spatial separation when two sound sources are delivered over headphones. More recently, McKinley and Ericson demonstrated the advantage of using spatial separation when up to four messages are delivered by an array of speakers in an anechoic chamber. The purpose of the experimental portion of this research was to determine if a similar advantage existed for up to four messages that are presented through headphones.

The working hypothesis for this experiment was that participants would accurately respond to overlapping messages more frequently if the messages were spatially separated. The testing of this hypothesis required preparation in the form of a pilot study. This initial study utilized less than half the number of participants of the final experiment and focused on graduate students who had specialized in Human Factors research. The intention was to collect suggestions from participants who were aware of experimental design principles, and to use those suggestions to improve the effectiveness of the protocol for the final study.

2. Messages

Three-hundred-sixty messages were scripted using the same basic template. Similar to Webster and Thompson's experiment with overlapping messages, each message contained the call sign of the person being addressed and the call sign of the person speaking. Instead of a reference to a visual display, however, the message contained a short sentence that ended with a coordinate. Each coordinate was composed of the combination of an alphabetical and a numeric component. For example, a speaker designated as "Yankee Two" might say, "Yankee One, this is "Yankee Two". Attacking

target at Echo Six. Over!" The call signs of the potential message sources were established as "Control", "Zulu One", "Yankee Two", and "Yankee Three". "Yankee One" was set aside as the call sign for the participant, so any messages addressed to this call sign would be designated as target messages. Messages addressed to one of the other entities were referred to as distracter messages.

"Control" was described as an abstract entity that was superior to the participant. "Zulu One" was described as a peer, while "Yankee Two" and "Yankee Three" were referred to as subordinates. This meant that "Control" would address "Yankee One" or "Zulu One". "Zulu One" would address "Control" or "Yankee One". "Yankee Two" and Three would address "Yankee One" or each other.   These relationships are shown in the following table.

Call Sign	**Addresses Messages to**
Control	Yankee One, Zulu One
Zulu One	Yankee One, Control
Yankee Two	Yankee One, Yankee Three
Yankee Three	Yankee One, Yankee Two

Table 1. Call Sign Relationships

Coordinates were arranged with the numbers one through eight on one axis and the letters A (Alpha) through H (Hotel) on the other axis. The portion of the message before the coordinate was extraneous material that was intended to provide a generic military context for the experiment. References to attacking, moving, detecting, etc. did not require any response or acknowledgement from the participant. Additionally, each speaker used only two phrases before giving a coordinate; one phrase for target messages and one for distracter messages. The only variation between messages in the same category was in the coordinate.

Two sets of messages were recorded. The first set contained 60 messages from "Control" and 60 messages from "Zulu One". Target and Distracter messages were

evenly divided, so each voice had 30 of each. The second set of messages utilized all four call signs ("Control", "Zulu One", "Yankee Two", and "Yankee Three"). Each speaker had 15 target messages and 45 distracter messages. Like the two-voice set, this allowed for 60 combinations of messages.

Messages were recorded with a standard PC microphone on a Dell Dimension 8100 using a SoundBlaster Live audio card. Sonic Foundry's Sound Forge 5.0 was used to record, store, and edit the messages in Microsoft's Wave file (.wav) audio format. More specifically, messages were recorded as RIFF waves (PCM), at a 44,100 Hz sampling rate in 16-bit mono. Peak intensity was adjusted for each message to standardize the sound level between competing messages. Messages were presented over headphones at approximately 55- 60 dB in a room with background noise at 45 dB.

3. Hardware

Messages were presented over a pair of hi-fidelity, high definition Sennheiser HD 570 headphones. Localization was performed by an AuSim GoldServe Sound Localization server. This system was capable of performing real-time localization with multiple sound sources by synthesizing cues such as the interaural time and intensity differences. It used both C++ and JAVA application programming interfaces (API) and came bundled with a set of client-server applications. During the pilot study, all interfaces were run on a Dell Dimension 8100 client computer that was connected to the server using the RS-232 communications protocol.

4. Software

The primary tool used for message playback was an AuSim client application called “Nordjorvik”. This program allowed the user to define coordinate locations for multiple sound sources and save them to a file. When the file was loaded, a command was sent to the server for each source instructing it to play the pre-defined wave file.

For data collection, a Microsoft Access database was used to collect participant responses. This data was imported into Excel where responses were graded with a series of conditional, or if-then, functions. Some rudimentary analysis was also done in Excel, though the majority of the statistical models were built in S-plus.

5. Participants

Participants included three women and eight men. All were either active duty military or veterans and had at least a bachelor's degree. Ten of the eleven participants were graduate students. None of the participants reported hearing abnormalities.

6. Procedure

Participants were asked to sit at the client computer, read a set of experimental instructions, and sign participant consent forms. The instructions described the basic purpose of the study, listed the possible call signs, and illustrated the coordinate system. Further explanation was provided by the experimenter and the participant was asked if they had any additional questions. The experimenter then demonstrated the use of Nordjorvik and the Access form that was used to collect data. For each trial, the participant was expected to load the appropriate file and listen to the messages. They were then asked to select the speaker that addressed them and the coordinate from the corresponding message. This was accomplished with the use of drop down menus that listed all of the possible answers for each category. Finally, the participant used the <enter> key to advance to the next record and the new record number was used as an index to load the next trial.

Each participant listened to 120 sets of messages. Half of the sets used two overlapping messages, while the other half used four overlapping messages. The first six participants had messages presented without spatial separation. The last five participants listened to messages with separation. Two voices at a time were placed at 45 degrees and 135 degrees. Four voices were placed at 45, 135, 225, and 315 degrees.

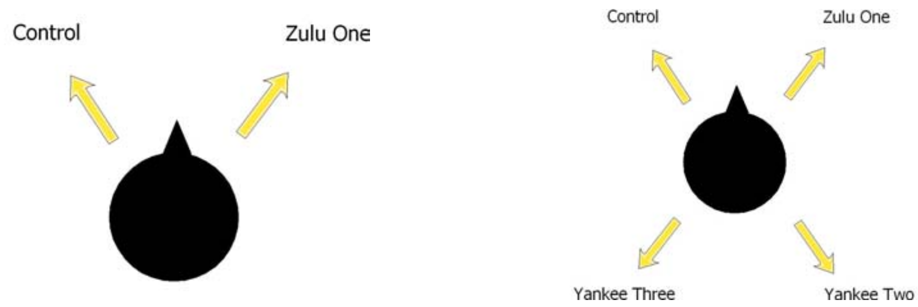

Figure 1. Placement of sound sources with two and four speakers

The experimental script was identical for each of the participants. Combinations of messages had been determined randomly using a program written in the JAVA language. For both the two and four message trials, the program randomly selected an element from an array of 60 objects without replacement. For the two-message trials this array was populated with 30 ones and 30 twos. For the four-message trials, there were 15 ones, 15 twos, 15 threes, and 15 fours. This insured that an equal number of target messages would be delivered by each voice.

The selected element from these groups determined which voice would deliver the target message. For example, in the two voice trials, if a one was drawn, then the target message would come from the group of target messages spoken by Control and the distracter would come from the group of distracter messages spoken by "Zulu One". If a two was drawn, the target message would come from the group of target messages spoken by "Zulu One" and the distracter would come from the group of distracter messages spoken by "Control".

With the four voice trials, there were four cases that were used after the initial draw. For example, if a three were initially drawn, then the program would select a target message from "Yankee Two's" list of target messages. Then it would select a distracter message from the distracter lists of "Control", "Zulu One", and "Yankee Three". The end result was that each voice delivered the target message 15 times for a total of 60 trials. By extension, every voice had to serve as a distracter in the remaining 45 trials.

This process was repeated until a script was generated that contained 120 trials, two sets of 60, and utilized all 360 messages. A hand check was performed to insure that no voice was selected to deliver the target message more than five times in a row. The results of this script were hard coded into the Nordjorvik .TCD files, which were loaded sequentially by the participant during the experiment.

Responses to each trial were stored in a database table that had one column for the speaker response, one for the alphabetical coordinate, and one for the numeric coordinate. Once the data was moved to Excel, a logical test was used to compare the participant's response to the correct answer. The comparison reduced the responses to binary variables.

B. ANALYSIS

1. Qualitative Observations

There were a number of observations made by the experimenter and participants that influenced the analysis of the pilot data. Certain areas of concern also affected the design of the final experiment. Comments were generally divided into two categories. The first category consisted of broad procedural issues, including the data collection interface. The second category focused on issues with the message files and the process of listening to the individual trials.

The main procedural issues were related to the mechanisms for collecting data and loading trials. Requiring participants to load their own trials was considered both tedious and a potential source of errors. The method of advancing to the next record was also confusing for many users. If they filled in the response fields out of order, then they would have to hit <enter> more than once to enter data for that trial. There was also a button at the bottom of the form that advanced the record, but it was small and difficult to distinguish from nearby buttons. Two users specifically mentioned that the use of two input modalities increased the mental effort and decreased the speed of data collection. Response time was not measured or analyzed, but the number of trials was large enough

that participants were motivated to move along at a steady pace. As a result, they tended to express frustration with aspects of the interface that slowed them down.

The length of the experiment was also mentioned as a possible influence on trial to trial differences in accuracy. Specifically, there was a concern that fatigue or momentary lapses in concentration would cause errors that were unrelated to the treatment conditions. However, it must also be remembered that sustained vigilance is a major part of task performance in the real world. Similarly, the large number of trials also introduced the possibility that a participant would be more accurate as they progressed through the trials. This potential for a learning or fatigue effect could unduly affect trial-to-trial probabilities of success.

2. Cochran's Test for Related Observations

An experimental design technique, called "blocking", can be used to examine the effectiveness of a group of treatments. In order to address the question of trial-to-trial probabilities of success, it is possible to look at the trial number as the treatment and determine whether all treatments are equally effective.

For each measure of accuracy, a matrix of ones and zeros was constructed. The rows of the matrix, also known as the blocks, corresponded to individual participants. The treatments, which were the trial numbers in this case, formed the columns. C_j is the total for column j, R_i is the total for row i, c is the number of columns, and N is the total number of observations. The following formula can be used to test the null hypothesis that all treatments are equally effective (Conover, 1999, 251):

$$T = c(c-1)\frac{\sum_j \left(c_j - \frac{N}{c}\right)^2}{\sum_i R_i \left(c - R_i\right)} \qquad (3.2)$$

The statistic for this test is difficult to calculate by hand because the matrices for the pilot data are either 6 x 60 or 5 x 60. Although this test is not available in S-Plus, SPSS, or Minitab, it can be executed in S-plus with a series of command line instructions provided by Professor Robert Read of the Naval Postgraduate School. The example in figure 2 shows how T was calculated using speaker identification as the measure of accuracy and response data from the participants who received spatialization as the blocks. This particular set of data only applies to the two voice trials.

```
> start.treat_c(120*6:10)
> start.treat
[1]  720  840  960 1080 1200
> ind.2vtreat_NULL
> for (j in 1:5) ind.2vtreat_c(ind.2vtreat, start.treat[j]+1:60)
> speak.2vtreat_matrix(Pilot.Data[ind.2vtreat,"Speaker"],60,5)
> speak.2vtreat_matrix(as.numeric(speak.2vtreat),60,5)
> speak.mat_t(speak.mat)
> speak.2vuntreat_t(speak.2vuntreat)
> RR_apply(speak.2vuntreat,1,sum)
> CC_apply(speak.2vuntreat,2,sum)
> N_sum(RR)
> TT_60*(59)*sum((CC-N/60)^2)/(sum(RR*(60-RR)))
> TT
[1] 68.0438
> 1-pchisq(TT,59)
[1] 0.1965179
```

Figure 2. Sample S-plus code for Cochran's Test

The last line of this code provides the p-value for a test conducted with the chi-squared distribution and c-1 degrees of freedom. At a significance level of .05, the null hypothesis was not rejected, which means that the treatments were equally effective. In this case, it indicates that the individual trials were equally likely to produce a correct response.

This test was conducted on the speaker, alphabetical coordinate, and numerical coordinate measures of accuracy. Each of these groups was further subdivided by number of voices and categorized by spatialization. Initially, the set using two voice trials with the speaker identification was one of only two groups of data that did not lead to the rejection of the null hypothesis. This changed, however, when the first five trials

were excluded from the analysis. Unfortunately, the change was only observable with the two voice data. The following table summarizes the results of these tests.

Number of Voices	Spatialization	Accuracy Measure	p-value	Conclusion $\alpha = .05$
Two	No	Speaker	.197	Equally Effective
Two	Yes	Speaker	.822	Equally Effective
Two	No	Alpha	.158	Equally Effective
Two	Yes	Alpha	.296	Equally Effective
Two	No	Numeric	.778	Equally Effective
Two	Yes	Numeric	.379	Equally Effective
Four	No	Speaker	.042	Not Equally Effective
Four	Yes	Speaker	.024	Not Equally Effective
Four	No	Alpha	.000	Not Equally Effective
Four	Yes	Alpha	.005	Not Equally Effective
Four	No	Numeric	.000	Not Equally Effective
Four	Yes	Numeric	.093	Equally Effective

Table 2. Results of Cochran's Test

These results show that the small learning effect that may have been present in the two voice trials could have been eliminated with a short practice session. They also show that there were one or more factors that caused the probability of success for the four voice trials to be inconsistent. The problem, however, is that there is no way to tell how much of the effect was due to learning, how much was due to fatigue, and how much was due to other causes There is also no way to tell from this test whether the magnitude of the effect is a cause for concern.

3. Graphical Examination of the Learning Effect

Time series plots were used to examine cumulative accurate responses over the course of sixty trials. The total number of correct responses for each participant was normalized to one, so that multiple participants could be compared on a single plot. Without a learning effect, each line should rise relatively evenly from zero to one. Runs of multiple trials without a new success result in plateaus that can give the line a step-wise appearance.

Figure 3 shows a plot for the six participants who listened to overlapping messages without spatialization. Additionally, the plot is based on the speaker identification variable during the two voice trials. Each line represents the progress of an individual participant. Notice that even though most of the lines are relatively straight, one of the lines dips significantly during the first fifteen trials. This dip is caused by several long periods at the beginning of the sequence in which this participant had no successes. This type of trend suggests a learning effect for that participant.

According to Cochran's Tests, there should not be major trial-to-trial effects in this particular subset of the data. The problem is that this test looked at the participants as a whole. Data was blocked by participant, but the test still had to produce a single statistic for the entire group, which means that the differences between individuals could be masked by this aggregation.

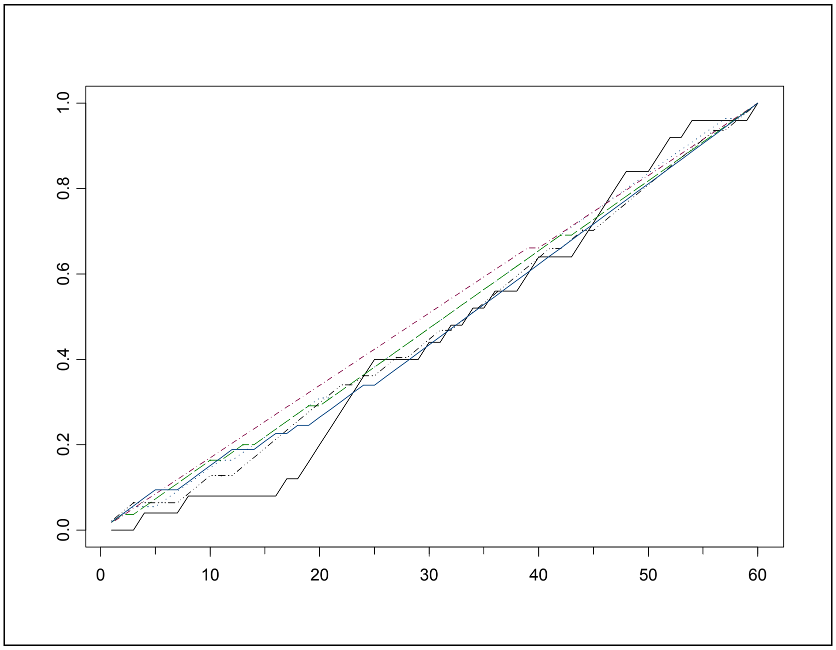

Figure 3. Time Series Plot. Two voices, Untreated, Speaker Identification

In general, these plots confirmed the results of Cochran's test. Learning effects were not as noticeable in the two voice trials as would have been expected. Additionally they were normally confined to one or two participants. In the four voice trials, there were frequently longer plateaus, but this appears to have been a function of the task difficulty and not indicative of a particular trend. An example of this is shown in Figure 4.

The reason the four voice lines look more like stepwise functions is that participants tended to accumulate far fewer successes than they did in the two voice trials. As a result, a single new success would cause a larger jump in the proportion of total successes. For example, in the two voice trials it was not uncommon for a participant to give more than fifty accurate responses for many of the measures of accuracy. This meant that each success in the time series plot would result in an increase of two percent or less. In contrast, a single success with the four voice trials could result in an increase of an increase of more than five percent.

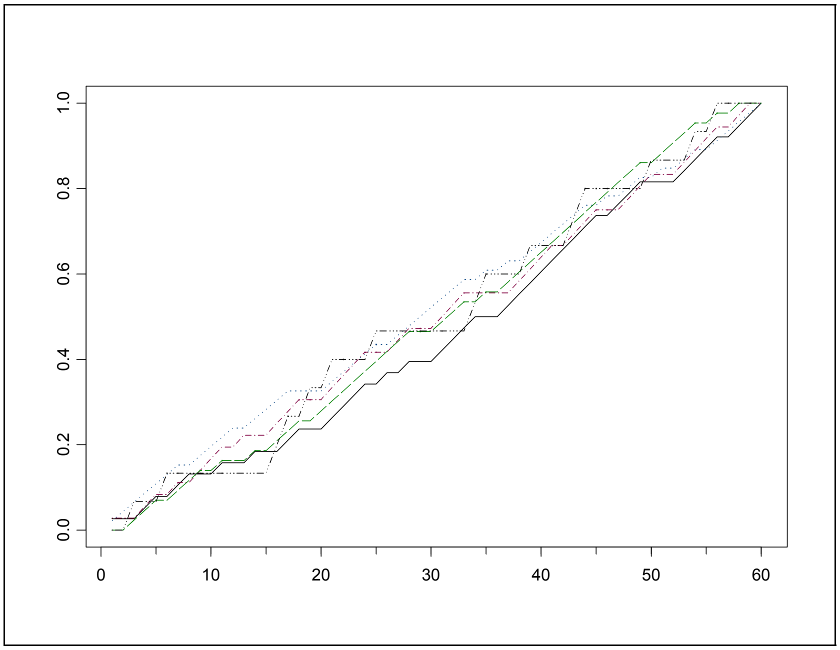

Figure 4. Time Series Plot. Four voices, Treated, Speaker Identification

For the most part, the plateaus for the four voice time series plots did not exhibit a noticeable trend. One exception to this rule was the plot for the participants who received no spatialization, and who attempted to identify the alphabetical portion of the coordinate with four overlapping messages. This plot is shown below as Figure 5 and appears to demonstrate a decrease in accuracy at the end of the sequence.

An explanation of this and similar effects could serve as a research topic on its own. For example, it is possible that users became fatigued more easily when spatialization was not used. For the purposes of this analysis, however, it is sufficient to confirm the results of Cochran's test, which showed that there are frequently variations in accuracy that are attributable not just to spatialization, but also to the progression in the trial sequence. Furthermore, it is important to emphasize that these trends did not affect all participants equally.

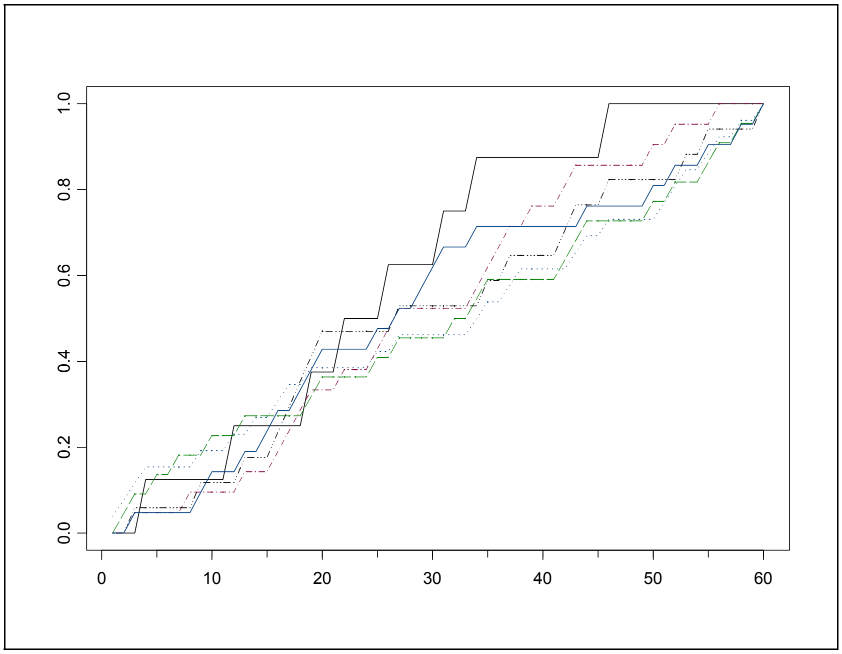

Figure 5. Time Series Plot, Four voices, Untreated, Alphabetical Coordinate

2. Chi-squared Tests for Independence

A chi-squared test for independence was the first quantitative method used to analyze the results of the pilot study. The number of responses to each measure of accuracy were divided into four cells. The columns of a 2x2 matrix were used to separate responses from spatialized (treated) and non-spatialized (untreated) trials. The rows were used to sort correct responses from incorrect responses. Figure 6 shows the form of the resulting contingency table.

	Treated	Untreated	
Correct	O_{11}	O_{12}	R_1
Incorrect	O_{21}	O_{22}	R_2
	C_1	C_2	**N**

Figure 6. 2 x 2 contingency table

In this case the column totals are fixed because the number of treated and untreated trials were known before hand. The row totals, however, are random because the number of correct responses was not known until the experiment was conducted.

The null hypothesis for this test states that the rows and columns are independent. This can be expressed more formally as P(row i, column j) = P(row i) * P(column j). In this case, the null hypothesis is that the probability of a correct response is independent of spatialization. A test statistic can be constructed by comparing the observed values of the cells to the values that would be expected under the assumption of independence. The expected value for a cell is found by dividing the product of the cell's row (R_i) and column (C_i) totals by the total number of observations (N). The following formula is then used to derive the test statistic:

$$T = \sum_i \sum_j \frac{(O_{ij} - E_{ij})^2}{E_{ij}} \tag{3.1}$$

The null distribution of this statistic is given approximately by the chi-squared distribution with (r-1)(c-1) degrees of freedom. According to W.J. Conover, the exact distribution is very difficult to find and the approximation is normally satisfactory. (Conover, 1999, pp. 204-205)

This test was applied to participant responses for four measures of accuracy. Each measure was based on the correct identification of a component of the target message. The first measure counted correct identifications of the person delivering the message (speaker). The second measured identification of the first part of the coordinate (alpha) while the third measured the second part of the coordinate (numeric). The last measured correct identification of the whole coordinate (aggregate).

At a .10 significance level, this test indicated that the proportion of accurate responses was dependent on spatialization for several measures of accuracy. These included the aggregate coordinate measure in the two voice trials, and the identification of the speaker, alphabetical component, and numeric component in the four voice trials.

It is important to note two things. First, the aggregate measure was not examined for the four voice trials because the task was difficult enough that there were no responses that correctly identified both portions of the coordinate. Second, the test indicated that spatialization and accuracy were independent for the speaker, alpha coordinate, and numeric coordinate measures under the two voice trials.

2 voice (correctly identify speaker)

	Treated	Untreated		E_{ij}		T	p-value
Correct	251	294	545	247.7	297.3	0.455	0.500
Incorrect	49	66	115	52.3	62.7		
	300	360	**660**				

2 voice (correctly identify alphabetic component of coordinate)

	Treated	Untreated		E_{ij}			
Correct	229	258	487	221.4	265.6	1.842	0.175
Incorrect	71	102	173	78.6	94.4		
	300	360	**660**				

2 voice (correctly identify numeric component of coordinate)

	Treated	Untreated		E_{ij}			
Correct	231	270	501	227.7	273.3	0.358	0.550
Incorrect	69	90	159	72.3	86.7		
	300	360	**660**				

2 voice (correctly identify entire coordinate)

	Treated	Untreated		E_{ij}			
Correct	220	240	460	209.1	250.9	3.443	0.064
Incorrect	80	120	200	90.9	109.1		
	300	360	**660**				

Figure 7. Chi-squared tests for 2 voice trials

4 voice (correctly identify speaker)

	Treated	Untreated		E_{ij}		T	p-value
Correct	178	170	348	158.2	189.8	9.6295	0.0019
Incorrect	122	190	312	141.8	170.2		
	300	360	**660**				

4 voice (correctly identify alphabetic component of coordinate)

	Treated	Untreated		E_{ij}			
Correct	159	115	274	124.5	149.5	29.8788	0.0000
Incorrect	141	245	386	175.5	210.5		
	300	360	**660**				

4 voice (correctly identify numeric component of coordinate)

	Treated	Untreated		E_{ij}			
Correct	154	107	261	118.6	142.4	31.9675	0.0000
Incorrect	146	253	399	181.4	217.6		
	300	360	**660**				

Figure 8. Chi-squared tests for 4 voice trials

This approach is valuable as a means of conducting exploratory analysis. It presents strong evidence that accuracy is dependent on spatialization with four simultaneous messages, but it provides little evidence that the same relationship exists with only two messages. One of the problems with the chi-squared test, however, is that it is generally considered a procedure of low power. In other words, there is an increased chance that the null hypothesis would not be rejected, even if it should be. In this case there is a possibility that dependence exists for the two-voice condition, but the test failed to detect it.

Another form of analysis is valuable for two reasons. First, it would provide a second opportunity to evaluate the results of the trials that used two voices at a time. Second, a test that can quantify the impact of multiple factors could ease any concerns that a confounding variable skewed the chi-squared results for the four voice trials. Given the extremely low p-values for those tests, it is unlikely that the conclusion will change, but it would still be interesting to quantify the relative influence of spatialization along with other variables that may have affected the probability of successful identification.

5. Logit Regression

Linear regression is frequently used to fit a line to a set of observations that can be described with an independent and dependent variable. If the dependent values are placed on the y-axis of a graph and the independent values are placed on the x-axis, then the slope and intercept of the line can be used to describe the relationship between the two variables. Multiple regression allows for more than one independent variable to be used in the same type of equation. This approach could be beneficial for exploring the causal relationship between a measure of accuracy and multiple predictors, but there is a complication. If accuracy is measured as a binary variable, then regression would simply fit a straight line through two groups of observations. One group would take on the value of zero and the other would take on the value of one. A slope and intercept would be generated, but they would not form a good fit with the original data. Specifically, any line with a non-zero slope would predict y-values that were less than zero, or greater than one, at some reasonable x-value (Hamilton, 1992, p.220).

In order to form a line that fits binary data, we need a function that only takes on values between zero and one. A natural function to use in this type of situation is based on the probability that a particular observation will have a y-value of one. Probabilities can only take on values between zero and one and they have a useful interpretation for this analysis. Specifically, an equation could be developed that would predict the probability of an accurate response given a set of conditions that is defined by the independent variables. In other words, variables such as spatialization, trial number, and participant number could be used to predict the probability of an accurate response.

If the probability of achieving an accurate response is called P, then the odds that a response variable equals one is:

$$\theta(Y=1) = \frac{P}{1-P} \tag{3.3}$$

Taking the natural logarithm of this expression gives the log odds or logit. Logit regression is essentially multiple regression with the logit as the response variable. In the following equation, the logit (L) is a linear function of the independent (x) variables.

$$L = \beta_0 + \beta_1 X_1 + \beta_2 X_2 + \ldots + \beta_{k-1} X_{k-1} \qquad (3.4)$$

Though equation 3.4 is a linear function, converting the logit to a probability with equation 3.5 creates a non-linear probability function with values between zero and one. (Hamilton, 1992, pp.220-221)

$$\hat{P} = \frac{1}{1+e^{-L}} \qquad (3.5)$$

This technique can be accomplished with the S-plus statistical package by building a generalized linear model (GLM) based on the binomial family. As an example, the following S-plus output shows the summary for a logit regression model.

```
Call: glm(formula = Alpha ~ Participant + Trial + Spatialization, family = binomial, data
= Pilot.4vall)
Deviance Residuals:
       Min         1Q    Median       3Q      Max
 -1.378632 -0.9946176 -0.800052 1.146946 1.698117

Coefficients:
                Value  Std. Error    t value
(Intercept)     0.562489706 0.361589855  1.5556015
Participant    -0.126599492 0.051937951 -2.4375142
Trial          -0.003058066 0.004692248 -0.6517272
Spatialization  0.791364437 0.167670520  4.7197590

(Dispersion Parameter for Binomial family taken to be 1 )
Null Deviance: 895.8559 on 659 degrees of freedom
Residual Deviance: 859.4353 on 656 degrees of freedom
```

Figure 9. Logit Regression. Example of Coefficient Estimates

This model estimates the logit for successful alphabetical coordinate identifications and uses the participant number, trial number, and spatialization as predictors. The number of voices is not used because the model was built only on the data from the four voice trials.

Coefficient estimates for these types of models show the direction and magnitude of a variable's effect on the log odds of success. The high positive value for spatialization in figure 9 suggests that it had a positive impact on the chance of success. The corresponding t-value can be used to test the hypothesis that the true value of the coefficient is zero. For eleven degrees of freedom, values greater than 2.20 or less than -2.20 indicate that this hypothesis would be rejected at the .05 significance level. In this case, the t-value for spatialization indicates that the term is significant.

An important consideration with any type of statistical model is how well it fits the actual data. For a logit regression model, an analysis of deviance can be used to determine goodness of fit. Figure 10 shows this analysis for the same model that was presented in figure 9.

```
Analysis of Deviance
Binomial model
Response: Alpha

Terms added sequentially (first to last)
               Df Deviance Resid. Df Resid. Dev   Pr(Chi)
NULL                             659   895.8559
Participant     1 12.65796       658   883.1980 0.0003740
Trial           1  0.40991       657   882.7881 0.5220169
Spatialization  1 23.35274       656   859.4353 0.0000013
```

Figure 10. Logit Regression. Example of Analysis of Deviance.

The highlighted p-value indicates that this model would be considered a good fit at the .05 significance level. It is important to emphasize that terms were added to the model sequentially and the p-value on a particular line indicates the fit of a model based on that term and the ones above it. The decision to remove a term, however, should not be based solely on this criterion.

Similar models were built for each of the measures of accuracy with data from both the two voice and four voice trials. Each model had a significant positive coefficient for spatialization. The fit of the models varied with the inclusion of certain terms. In general, these models suggest that spatialization had a quantifiable impact on accuracy for both the two and four voice conditions. It is tempting to go further and say that the variation among participants and between trials was insignificant compared to the effect of spatialization, but this data created several notable limitations for the regression models.

First, both trials and participants were originally treated as continuous variables. There is a valid interpretation for this approach because both variables were ordinal. In other words, the eighth participant in the experiment participated at a point that was twice as far from the beginning as the first. Similarly, the eighth trial out of sixty is twice as far into the sequence as the fourth. The problem is that this limits the type of differences that can be explored, particularly between participants. Viewing the relationship between trials as a simple linear function of their order has some meaning, but this is less interpretable for participants. The problem originated in the design of the pilot

experiment. Since some participants received spatialization and others did not, singularities were created when attempts were made to include both participants and spatialization in the model as factors.

Similarly, the relationship between participants and spatialization led to a high degree of correlation between the two variables, even when the participant number was treated as continuous. This raises the issue of multicollinearity, which can lead to unreliable coefficient estimates and inflated standard deviations. The solution to both of these problems was to conduct an experiment in which every participant received a combination of spatialized and non-spatialized trials.

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IV. FINAL EXPERIMENT

A. METHODOLOGY

1. Hardware

The most significant change to the hardware configuration was the addition of an inertial head tracker. Specifically, an InterSense InterTrax2 was mounted to the top of the participant's headphones and connected to the AuSim server via a USB port. This device was able to monitor the movement of the participant's head with three degrees of freedom (yaw, pitch, and roll). An AuSim application, called the AuSim Asynchronous Tracking Program (AuAST) was used to feed the raw data to Nordjorvik.

One of the disadvantages to headphone spatialization is that the sound sources move with the head. This can disrupt the illusion of spatialization and prevent the resolution of front-back confusion. The purpose of the head tracker was to improve the perception of localization for the spatialized trials.

2. Design Changes

Several major changes were made to the design of the pilot study experiment. One of the most significant was the generation of a new script that contained trials with three and four voices. The two-voice condition was eliminated for two reasons. First, an impression was formed during the pilot study that there was a large gap between the difficulty of two and four voice trials. This insight was supported by both qualitative observations from participants and by the difference in average accuracy rates. Specifically, the two voice trials seemed very easy for participants after they had learned to focus on the differences between the voices.

The second reason for eliminating the two-voice condition was to limit the length of the experiment. The natural question that arose from the differences in difficulty was whether three voices would be more like the two voices or more like four voices. The

problem was that the experiment would have been much too long if a two, three, and four voice condition were all used at the same time. The pilot study results were not conclusive, but they suggested that this experimental design would ultimately duplicate these results or earlier experiments that used two voices.

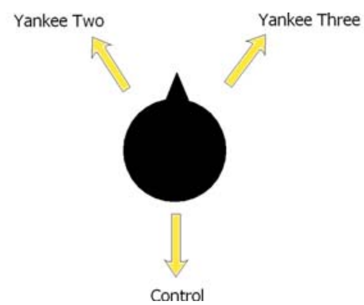

Figure 11. Placement of sound sources with three speakers

The second major change was the introduction of a balanced design that would require each participant to listen to a combination of spatialized and non-spatialized trials. Alterations were made to the original script generator to include the addition of three voice trials and to add a flag to the output which would be used to determine if a specific trial was spatialized or not. The number of flags insured that half of the trials would be spatialized and they were applied at random intervals to the list of trials. Additionally, the random ordering was structured so that there could not be a run of more than six trials that would have the same spatialization condition.

A third major change involved the use of a new normalization method to equalize the apparent loudness of the message files. One observation from the pilot study was that the peak volume method had not adequately compensated for volume differences between the four voices. As a result, a more comprehensive method was applied using the root mean squared (RMS) intensity over the entire length of the message. All sounds were normalized to -12dB. Scan parameters included an attack time of 10 milliseconds and a release time of 500 milliseconds. Additionally, portions of a message that were under a threshold of -70dB were ignored in the calculations.

Minor changes to the experimental design included the transfer of sound files from the client to the server. Running Nordjorvik from the server reduced the latency from the RS-232 cable and helped improve synchronization during message playback. Control of the trial progression was also passed to the experimenter. This produced two benefits. First, there was less chance that the experimenter would become confused and run the wrong trial. Second, the participant was free to focus on responding to the messages. The last set of minor changes included several revisions to the data collection form. A large button was added under the response fields to advance the record. A reminder of the participant's call sign and an admonition to focus on the target message were displayed on the form. Two diagrams were also added to show the positions of the message sources for the spatialized trials.

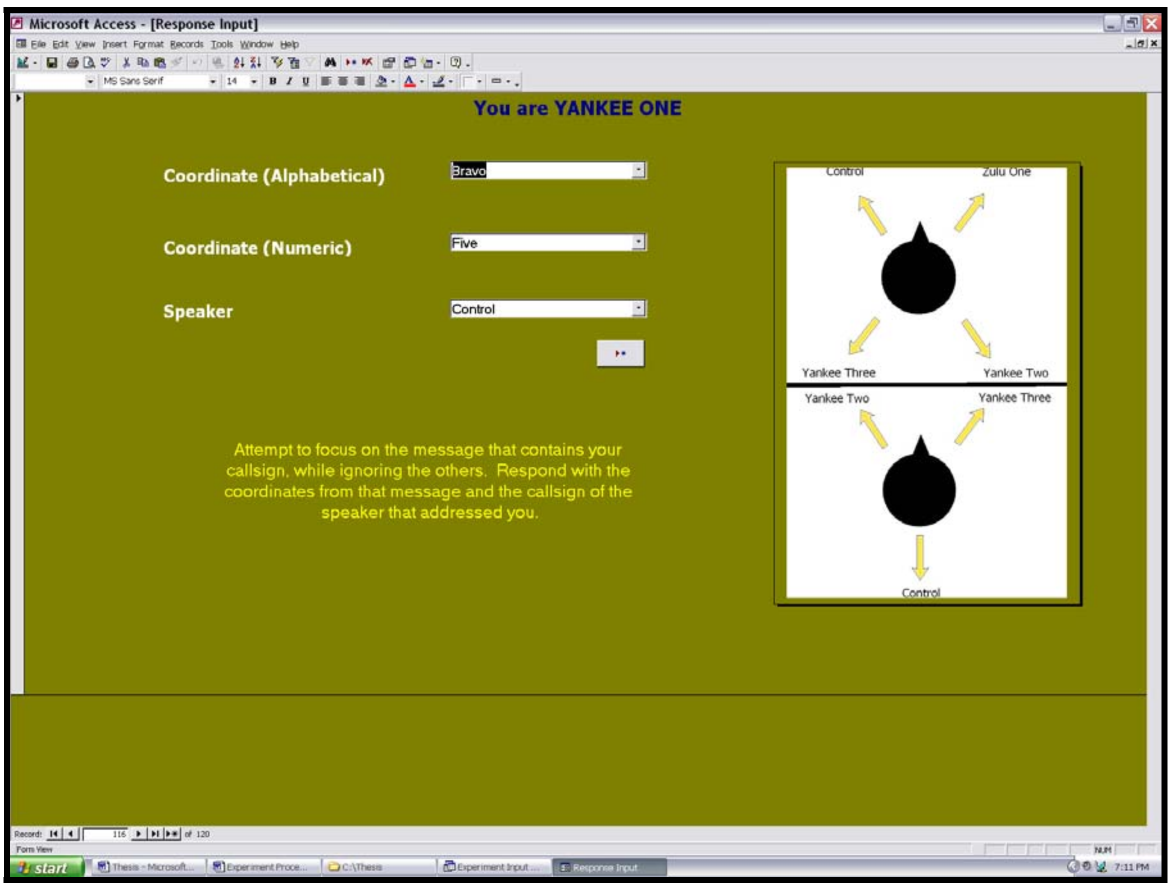

Figure 12. Screenshot of Response Input Form

Finally, an orientation and short set of practice trials were added in the hopes of decreasing learning effects. This portion included an opportunity to listen to each of the

speakers separately, an example of three speakers with and without spatialization, instructions for new hardware, and ten practice trials. The practice trials were divided evenly between three and four voices.

The practice session was followed by a testing period that was very similar to the pilot study. The participant would read the record number and the experimenter would load the corresponding trial. Next, the participant would listen to the messages and enter a response. Finally, the participant would advance the record and read the new record number. Similar to the pilot study, data collection consisted of 120 trials. The first sixty contained three voice messages, while the second 60 contained four voice messages.

3. Participants

Participants included two women and twenty-three men. The majority was active duty military, though three participants were civilians. All participants were over the age of 18 and had completed at least a bachelor's degree. None of the participants reported hearing abnormalities.

B. ANALYSIS

1. Qualitative Observations

Many attempts were made to isolate the effect of spatialization on response accuracy. These included the elimination of the RS-232 client-server connection, the application of RMS normalization, and the addition of practice trials. Despite these efforts there were anecdotal reasons to believe that differences between voices, trials, and participants continued to have an impact on accuracy rates.

The voice that delivered the target message appeared to be important in two ways. First, participants continued to claim that some voices were more intelligible than others. This appeared to be due to their position in space rather than the actual intensity of the source files. Both of these voices were placed to the sides and slightly behind the listener

in the spatialized trials. Specifically, "Yankee Two" was placed at 225 degrees and "Yankee Three" was placed at 315 degrees. Similarly, some participants claimed that they had a hard time hearing the voice for "Control" in the three voice trials when that voice was placed directly behind them (270 degrees).

The second issue with target voices was related to the problem of message synchronization. Even though changes to the hardware configuration had improved the amount of overlap between messages, there were still instances where one voice could be heard distinctly by itself. Sometimes this happened purely by accident. One source would be speaking while the other two or three were pausing. Other times, however, the there would be a short pause between the start of the first voice and the addition of subsequent voices. During the pilot study, this type of variation was examined as part of the trial-to-trial changes in the probability of success. In the final experiment, a decision was made to specifically analyze the effect of the target voices.

Differences among participants were expected, but there was one type of difference that appeared to be significant. Some participants seemed to make effective use of the head tracker, while others did not. Assuming that a listener could identify the speaker that had addressed their call sign, it was possible to focus on that message by turning an ear toward the corresponding position. For example, if a participant heard "Control" call them in the three voice trials, the rest of the message would become more intelligible if they turned their head toward their rear. Anecdotally, some participants seemed to acquire this skill quickly and use it to great effect. Many did not attempt to use it at all and a handful seemed to become confused when they used it. These differences were not anticipated and there is no way to analyze them specifically from the data that was collected. The best approximation that could be made was to study the effect that the participant variable had on accuracy.

2. Descriptive Statistics

At first glance, differences in the proportion of correct responses, conditioned on spatialization, appear significant. Figure 13 provides this data in a tabular format,

followed by three charts that give the same information with bar charts. The abbreviations represent the four measures of accuracy from the pilot study; speaker identification (Speak), alphabetical coordinate identification (Alpha), numerical coordinate identification (Num), and identification of the whole coordinate (Agg). In addition, there is a fifth measure for total accuracy. This variable was recorded as a one if all parts of the message were identified correctly and zero if any of the parts were missed. It is referred to as total, or complete, accuracy.

All Data	**Speak**	**Alpha**	**Num**	**Agg**	**Total**
Spatialized	0.59	0.51	0.49	0.45	0.43
Non-Spatialized	0.41	0.25	0.29	0.19	0.17

3 voice	**Speak**	**Alpha**	**Num**	**Agg**	**Total**
Spatialized	0.66	0.58	0.56	0.52	0.51
Non-Spatialized	0.51	0.30	0.37	0.26	0.24

4 voice	**Speak**	**Alpha**	**Num**	**Agg**	**Total**
Spatialized	0.51	0.43	0.42	0.37	0.36
Non-Spatialized	0.32	0.21	0.22	0.13	0.10

Figure 13. Summary Statistics

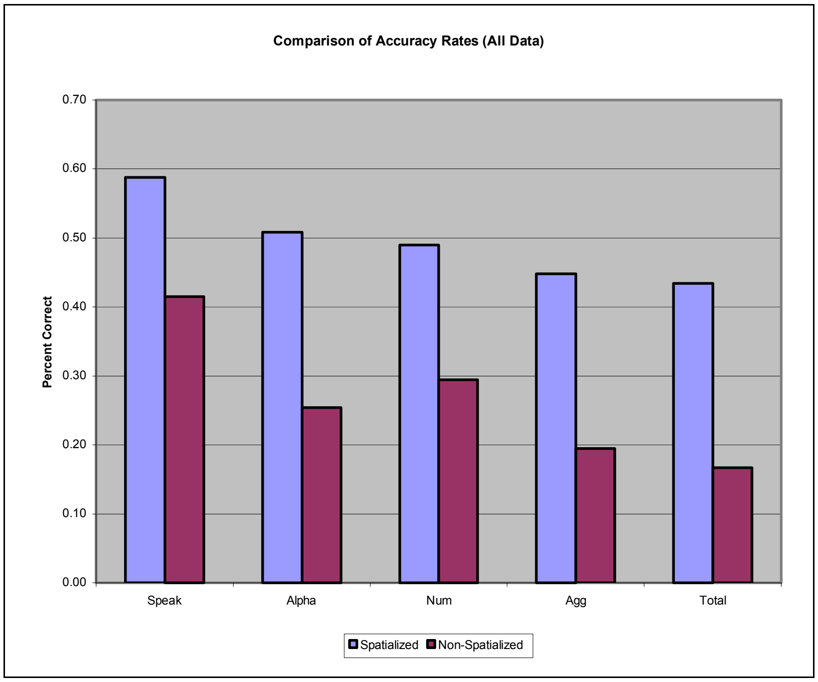

Figure 14. Comparison of Accuracy Rates (All Data)

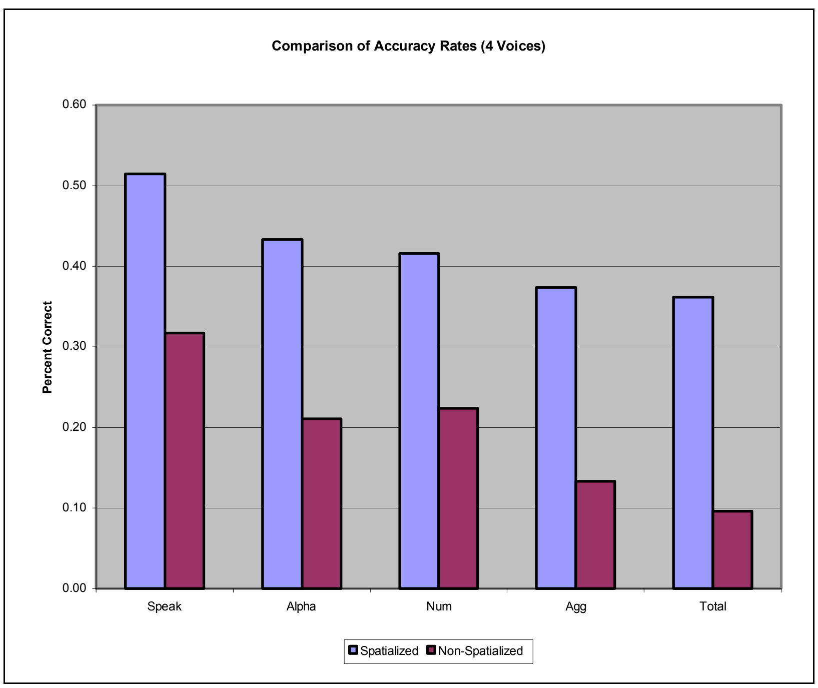

Figure 15. Comparison of Accuracy Rates (4 Voices)

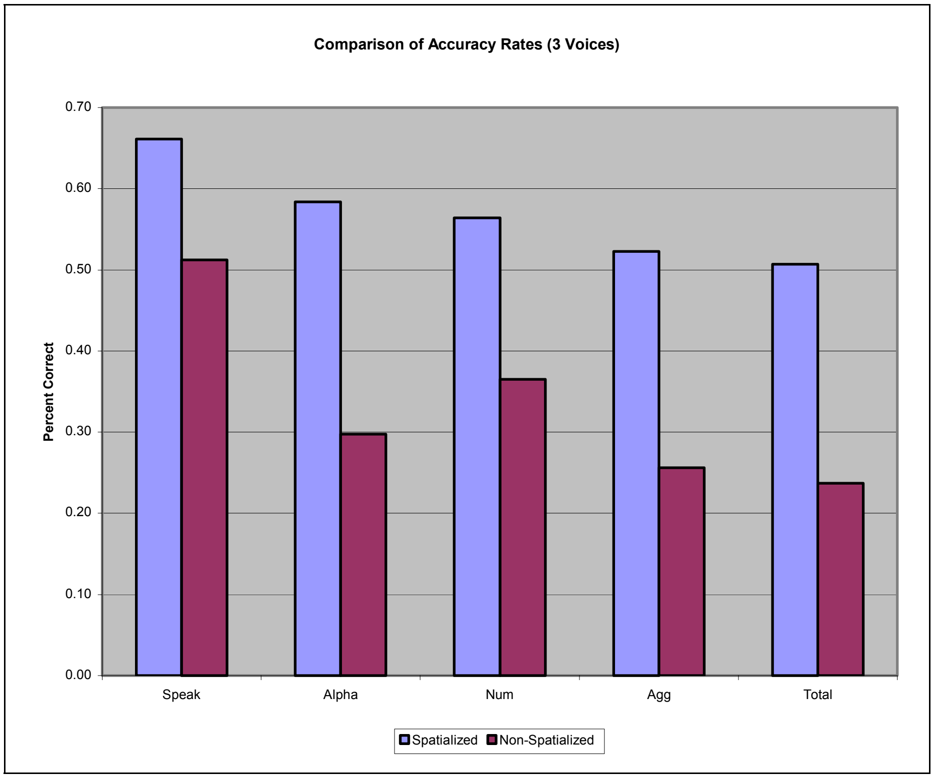

Figure 16. Comparison of Accuracy Rates (3 Voices)

Visually, these differences appear to be notable, but it is important to test their significance statistically. An approach similar to the one found in chapter 3 was utilized with an expectation that the new data would provide more definitive results. This assumption was based on in increase in the number of participants and the change to a balanced design in which each participant received both spatialized (treated) and non-spatialized (untreated trials).

3. Chi-squared Tests for Independence

The results of chi-squared tests, applied to both the three and four voice data, indicated very strong evidence for the dependent relationship between accuracy and spatialization. Every p-value was smaller than .0001, a threshold that far exceeds any reasonable test of significance. These results were most likely the result of two factors. First, there seems to be a genuine difference that is attributable to spatialization. Second,

a large amount of data was used. Twenty five participants might not seem like a large sample size, but the chi-squared test was based on the results of individual trials. This means that each test was able to utilize 1500 observations. Figures 17 and 18 present the results of this analysis.

3 voice (correctly identify all components)

	Treated	Untreated		E_{ij}		T	p-value
Correct	380	178	558	279.0	279.0	116.4418	0.0000
Incorrect	370	572	942	471.0	471.0		
	750	750	**1500**				

3 voice (correctly identify speaker)

	Treated	Untreated		E_{ij}		T	p-value
Correct	496	384	880	440.0	440.0	34.4868	0.0000
Incorrect	254	366	620	310.0	310.0		
	750	750	**1500**				

3 voice (correctly identify whole coordinate)

	Treated	Untreated		E_{ij}		T	p-value
Correct	392	192	584	292.0	292.0	112.1613	0.0000
Incorrect	358	558	916	458.0	458.0		
	750	750	**1500**				

3 voice (correctly identify alpha coordinate)

	Treated	Untreated		E_{ij}		T	p-value
Correct	438	223	661	330.5	330.5	125.0273	0.0000
Incorrect	312	527	839	419.5	419.5		
	750	750	**1500**				

3 voice (correctly identify numeric coordinate)

	Treated	Untreated		E_{ij}		T	p-value
Correct	423	274	697	348.5	348.5	59.4998	0.0000
Incorrect	327	476	803	401.5	401.5		
	750	750	**1500**				

Figure 17. Chi-squared analysis for 3 voice trials

4 voice (correctly identify all components)

	Treated	Untreated		E_{ij}		T	p-value
Correct	271	72	343	171.5	171.5	149.6821	0.0000
Incorrect	479	678	1157	578.5	578.5		
	750	750	**1500**				

4 voice (correctly identify speaker)

	Treated	Untreated		E_{ij}		T	p-value
Correct	386	238	624	312.0	312.0	60.1071	0.0000
Incorrect	364	512	876	438.0	438.0		
	750	750	**1500**				

4 voice (correctly identify whole coordinate)

	Treated	Untreated		E_{ij}		T	p-value
Correct	280	100	380	190.0	190.0	114.1917	0.0000
Incorrect	470	650	1120	560.0	560.0		
	750	750	**1500**				

4 voice (correctly identify alpha coordinate)

	Treated	Untreated		E_{ij}		T	p-value
Correct	325	158	483	241.5	241.5	85.1640	0.0000
Incorrect	425	592	1017	508.5	508.5		
	750	750	**1500**				

4 voice (correctly identify numeric coordinate)

	Treated	Untreated		E_{ij}		T	p-value
Correct	312	168	480	240.0	240.0	63.5294	0.0000
Incorrect	438	582	1020	510.0	510.0		
	750	750	**1500**				

Figure 18. Chi-squared analysis for 4 voice trials

The principal limitation to this analysis is the simplicity of the results. Though it supports the argument that spatialization improves performance, there is much more that can be done with the wealth of data that was collected from the final experiment. Again, regression provides an opportunity to examine the effect of other variables. Even better, coefficients based on log odds have a natural interpretation as the amount that a factor changes the probability of success.

4. Logit Regression

The pilot study was structured to determine if learning, fatigue, or other factors that affected the success rate were present. This structure confirmed that these types of effects existed, but it presented difficulties when attempting to confirm the effect of spatialization. In contrast, the final experiment was based on a more balanced design. The resulting data proved to be more conducive for focusing on the effect of spatialization.

One specific advantage was the ability to change the participant variable to a factor with 24 levels. In chi-square analysis for independence in the pilot study, the test only took one predictor variable into account and indicated that spatialization was not significant for the two voice trials. The logit regression model used a greater number of variables, albeit imperfectly, and suggested that spatialization was a significant predictor of success.

An example of this problem was also encountered with the data from the final experiment. Figure 19 shows a logit regression model with three variables used as predictors. Spatialization, called "Treat", is shown as having a significant positive effect in the presence of voices and trials. In this case, "voices" was a factor with two levels and "trials" was an ordinal variable. An analysis of deviance showed that the model passed the goodness of fit test with a p-value that was considerably smaller than .01, but there were several problems with the model. First, it was important to see if the sign or standard deviation of the coefficient estimates would change in the presence of other variables. Second, a large change in the magnitude of the coefficient for spatialization could be important. Figure 20 shows a more complicated model that included both participants and the target voice (source) as factors. Note that the Treat variable maintained a significant, positive coefficient estimate, but the magnitude was different.

```
Call: glm(formula = Speak ~ Voice + Treat + Trial, family = binomial, data = Final.Data)
Deviance Residuals:
       Min        1Q   Median       3Q      Max
 -1.593513 -1.138687 0.812157 1.137074 1.578598

Coefficients:
                   Value  Std. Error   t value
(Intercept) -0.430436596 0.136845816 -3.145413
      Voice -0.573490250 0.075988839 -7.547033
      Treat  0.364244018 0.037695658  9.662758
      Trial  0.007209083 0.002175212  3.314197

(Dispersion Parameter for Binomial family taken to be 1 )

    Null Deviance: 4158.862 on 2999 degrees of freedom

Residual Deviance: 3966.704 on 2996 degrees of freedom

Number of Fisher Scoring Iterations: 2
```

Figure 19. Logit Regression. Model with Three Predictors

```
Call: glm(formula = Speak ~ Voice + Treat + Trial + Participant + Source, family =
binomial, data = Final.Data)
Deviance Residuals:
       Min         1Q    Median        3Q      Max
 -2.515075 -0.8493125 0.2322847 0.8331919 2.634168

Coefficients:
                   Value  Std. Error     t value
(Intercept) -0.662312045 0.159592351  -4.1500237
      Voice -0.584496117 0.090429166  -6.4635796
      Treat  0.546746939 0.046128558  11.8526778
      Trial  0.008392205 0.002505463   3.3495627
   Participant1 -0.844521653 0.158073592  -5.3425853
   Participant2  0.115305538 0.086253435   1.3368226
   Participant3 -0.239956798 0.067879033  -3.5350651
   Participant4  0.016192190 0.047845969   0.3384233
   Participant5  0.236279194 0.038637267   6.1153186
   Participant6  0.078740054 0.031752741   2.4797876
   Participant7  0.171294716 0.028803175   5.9470775
   Participant8  0.143554177 0.025645789   5.5975730
   Participant9  0.074446979 0.022026796   3.3798369
  Participant10 -0.070547162 0.020534014  -3.4356245
  Participant11  0.147175569 0.020944305   7.0269972
  Participant12 -0.103798729 0.018595667  -5.5818771
  Participant13  0.068753433 0.015867493   4.3329740
  Participant14 -0.087622545 0.016038237  -5.4633526
  Participant15  0.078994544 0.014329410   5.5127562
  Participant16  0.042591720 0.012746497   3.3414452
  Participant17  0.042768872 0.012111301   3.5313193
  Participant18 -0.070397173 0.012462648  -5.6486528
  Participant19  0.056066687 0.011302528   4.9605439
  Participant20 -0.050934874 0.010793367  -4.7190905
  Participant21  0.048557049 0.010182409   4.7687192
  Participant22  0.042277350 0.009665747   4.3739349
  Participant23 -0.048274888 0.009487342  -5.0883470
  Participant24  0.022976518 0.008509901   2.6999747
    Source1 -1.064906148 0.084799400 -12.5579443
    Source2  0.009662149 0.038256846   0.2525600
    Source3 -0.200650780 0.026219696  -7.6526739

Residual Deviance: 3157.748 on 2969 degrees of freedom
```

Figure 20. Logit Regression. Model with Thirty Predictors.

The models in figures 19 and 20 suggest that spatialization increased the chance of success, but there was a second problem with this approach. Similar to the issue with the pilot data, where participant and spatialization were highly correlated, voice and trial were highly correlated in the final data. The reason is that the four voice trials always came after the three voice trials. The problem with this relationship is that it introduced the potential of multicollinearity again. The solution was to build models on subsets of the data. One group used the data from the three voice trials and the other group used data from the four voice trials. Additionally, a new variable was added to turn Trial into a factor. Instead of using 60 levels, the new variable, "Stage", had 12 levels. The first level corresponded to the first five trials, the second level represented trials six through ten, and so on.

Figure 21 shows the partial results of a logit regression model that used spatialization (Treat), trials (Stage), target voice (Source) and participants as factors.

```
Call: glm(formula = Alpha ~ Treat + Stage + Participant + Source, family =
binomial, data = f3vall)
Deviance Residuals:
       Min         1Q     Median        3Q      Max
 -2.566268 -0.6755575 -0.1975927 0.6615144 3.235951

Coefficients:
                   Value Std. Error     t value
(Intercept)     -0.499155389 0.07653958  -6.5215328
 Treat           1.263212777 0.09485824  13.3168482
 Stage1         -0.259662770 0.17957489  -1.4459860
.....
 Stage9          0.081708106 0.02761867   2.9584370
 Stage10        -0.004421301 0.02400394  -0.1841907
 Stage11         0.045472721 0.02048126   2.2202111
 Participant1   -1.037291766 0.24537299  -4.2274081
 Participant2    0.137001144 0.12994851   1.0542725
 Participant3   -0.423645895 0.12306863  -3.4423550
 Participant4    0.157889550 0.07069623   2.2333518
 Participant5    0.298009968 0.05735961   5.1954673
 Participant6    0.086177557 0.04715274   1.8276258
 Participant7    0.152941999 0.04087090   3.7420759
 Participant8    0.238028131 0.03989194   5.9668227
 Participant9    0.110452715 0.03248956   3.3996369
 Participant10  -0.177333609 0.03823750  -4.6376878
.....
 Participant24   0.094421456 0.01480635   6.3770905
 Source1        -0.234314454 0.09405247  -2.4913164
 Source2        -0.425853223 0.06000716  -7.0967073
```

Figure 21. Logit Regression. Alpha Response Accuracy (3 voices, partial output)

This model suggests that spatialization had a large positive effect on the ability to accurately identify the alphabetical portion of a coordinate in the three voice trials. In this particular case, it even had the coefficient with the greatest absolute value. Also, note the large t-value for "Treat". Similar to the results of the chi-squared analysis, this corresponds to a p-value that is very close to zero. Figure 22 shows that this model also passed the goodness of fit test.

```
Terms added sequentially (first to last)
               Df Deviance Resid. Df Resid. Dev   Pr(Chi)
   NULL                        1499    2058.269
   Treat        1 126.9351     1498    1931.334   0.00000000
   Stage       11  20.4466     1487    1910.887   0.03957924
   Participant 24 553.1791     1463    1357.708   0.00000000
   Source       2  61.4782     1461    1296.230   0.00000000
```

Figure 22. Analysis of Deviance. Alpha Response Accuracy (3 voices)

It is important to mention that this is also the first model that lacked coefficients that were highly correlated. It does not answer every possible question that could be asked with this type of experiment, but it captures the important aspects of the data that were collected. Unlike simpler models it is capable of showing the effect of spatialization in the presence of other variables. Most importantly, it was applied to all of the measures of accuracy for both the three and four voice trials with similar results. Table 2 provides a point estimate for the coefficient of the "Treat" variable, the standard error for the estimate, the corresponding t-value for the estimate, and the status of the goodness of fit from the analysis of deviance.

The full output from these models is included in Appendix I. The coefficients of other variables might be of some interest. In general, the variation between participants is expected and the presence of significant coefficients is not a surprise. The results for voices, however, is notable because it indicated that a trial was easier or harder depending on the voice that delivered the message. Finally, the stage, or progression through the trials, did not appear to have a large effect. There were some exceptions, but the coefficients for the levels of the stage factor tended to be either insignificant or significant and small. This is important because it shows that even if learning, fatigue, or other effects are present, their impact is normally small compared to other factors. It is

also worthwhile to repeat the observation that spatialization proved to be significant, even in the presence of these other factors that influenced the probability of success.

Measure	Effect of spatialization on log odds of success (estimate)	Standard Error of estimate	T-value (H_o: Effect equals zero)	Goodness of Fit (α=.01)
3 Voice				
Speaker	+0.7760	0.0837	9.2639	Passed (reject)
Alpha	+1.2632	0.0949	13.3168	Passed (reject)
Numeric	+0.8536	0.0855	9.9872	Passed (reject)
Aggregate	+1.3681	0.1046	13.0804	Passed (reject)
Total	+1.4491	0.1101	13.1555	Passed (reject)
4 Voice				
Speaker	+0.5965	0.0676	8.8251	Passed (reject)
Alpha	+0.8797	0.0795	11.0620	Passed (reject)
Numeric	+0.7085	0.0733	9.6664	Passed (reject)
Aggregate	+1.1712	0.0968	12.1030	Passed (reject)
Total	+1.6405	0.1277	12.8431	Passed (reject)

Table 3. Results of Logit Regression

The information from Table 2 can be used to present these results in a more intuitive format. First, the point estimate and standard error can be used to form a 99% confidence interval. Second, the treatment's contribution to the log odds of success can be converted into a probability. Note, however, that the resulting probability assumes a base rate of 50%. This is because the response variable is binary and there would be a 50% probability of success if there were no influences other than chance. Therefore, a variable with a coefficient of zero has no effect on the base chance of success in a logit

regression model. Variables with positive coefficients raise the probability above 50%. Variables with negative coefficients lower the probability below 50%.

For example, the term for spatialization in the three voice trials, with the alpha coordinate response, had a coefficient of 1.2632. Using equation 3.5, this number can be converted into a probability of .78. One interpretation of this result is that spatialization raised the chance of success by 28%, given the presence of the other conditions that were reflected in the model.

Table 3 presents the spatialization coefficient estimate and a 99% confidence interval based on the student t-distribution with 1461 degrees of freedom for the three voice measures and 1460 for the four voice measures. It also shows a conversion of these results into changes in the probability of success.

Measure	Effect of spatialization on log odds of success (estimate)	99% Confidence Interval for log odds		Effect of spatialization on probability of success (estimate)	99% Confidence Interval for probability	
3 Voice						
		Low	High		Low	High
Speaker	+0.7760	+0.5601	+0.9919	+18.48%	+13.65%	+22.95%
Alpha	+1.2632	+1.0184	+1.5080	+27.96%	+23.47%	+31.88%
Numeric	+0.8536	+0.6331	+1.0741	+20.13%	+15.32%	+24.54%
Aggregate	+1.3681	+1.0983	+1.6379	+29.71%	+24.99%	+33.72%
Total	+1.4491	+1.1651	+1.7331	+30.99%	+26.23%	+34.98%
4 Voice						
		Low	High		Low	High
Speaker	+0.5965	+0.4222	+0.7708	+14.49%	+10.40%	+18.37%
Alpha	+0.8797	+0.6747	+1.0847	+20.68%	+16.25%	+24.74%
Numeric	+0.7085	+0.5195	+0.8975	+17.01%	+12.70%	+21.04%
Aggregate	+1.1712	+0.9215	+1.4209	+26.34%	+21.54%	+30.55%
Total	+1.6405	1.3111	+1.9699	+33.76%	+28.77%	+37.76%

Table 4. Confidence Intervals for Log Odds and Probabilities of Success

V. CONCLUSIONS AND RECOMMENDATIONS

A. ANALYTICAL CONCLUSIONS

This research provides quantitative evidence that a spatialized headphone display can increase a listener's probability of accurately responding to more than two overlapping messages. Specifically, a chi-squared analysis of experimental data strongly supports the dependent relationship between accurate responses and spatialization. Additionally, the coefficient for spatialization in a logit regression model reinforces this conclusion and allows for the impact of this benefit to be quantified in terms of increases in the probability of success. The first half of this conclusion could have been assumed from prior experiments, but such an assumption would have required important environmental conditions to be ignored.

In particular, the inclusion of more than two voices reduces the degrees of separation that can exist between any two sources. Without adequate separation the apparent positions of two nearby sources could become indistinguishable. There was some concern that this might be the case with four spoken messages. The distinction between the left and right ear was obviously noticeable, but there was a possibility that it would be difficult to separate the two voices that were on the same side of the head. Despite the relative difficulty of attending to four messages, the spatialization scheme proved to be beneficial.

B. RECOMMENDATIONS FOR FUTURE STUDY

Anecdotally, the effective use of an inertial head tracker seemed to greatly improve the intelligibility of the target coordinate. One possibility for future study would be to compare the accuracy of a participant's responses with and without the tracker. The use of an inertial headtracker is significant, since the device is relatively inexpensive and is unaffected by metal structures as are more traditional electromagnetic headtrackers.

Another area for potential research is the use of individualized head related transfer functions. These measurements can improve the realism of localization perception and could theoretically have an impact on performance. Similar to the head tracking issue, the benefit of custom HRTFs could be examined by using them as a treatment effect.

Another logical extension of this study might involve the use of additional voices. At the least, some criteria should be established to determine what constitutes a minimally acceptable accuracy level. It is reasonable to conjecture that there is a point at which spatialization still provides a benefit, but that intelligibility is so low that the situation has no practical applicability.

It is also important to note that these same questions could be applied using some new measure of performance. Reaction time is an example of a response variable that could be used to explore more subtle difference because it is measured on a continuous scale. Care should be taken however, not to misrepresent the differences in these types of studies. Performance decreases measured in fractions of a second might be statistically significant, but they might not be meaningful in practical terms.

Finally, the development of context specific tests could be beneficial at this point. Certain tasks, such as head tracking might be more practical in some environments and less practical in others. It would also be interesting to test the efficacy of a spatialized sound display in combination with a visual component that indicates who a speaker is addressing or even the full text conversion of speech.

APPENDIX A. MESSAGES

This appendix contains the file names and contents of the messages that were used for both the pilot study and final experiment.

Speaker One (Control)

Target Messages (2 source trials)

File	Message
2101.wav	"Yankee One, this is control. Proceed to position Alpha One. Over"
2102.wav	"Yankee One, this is control. Proceed to position Bravo Two. Over"
2103.wav	"Yankee One, this is control. Proceed to position Charlie Three. Over"
2104.wav	"Yankee One, this is control. Proceed to position Delta Four. Over"
2105.wav	"Yankee One, this is control. Proceed to position Echo Five. Over"
2106.wav	"Yankee One, this is control. Proceed to position Foxtrot Six. Over"
2107.wav	"Yankee One, this is control. Proceed to position Golf Seven. Over"
2108.wav	"Yankee One, this is control. Proceed to position. Hotel Eight. Over"
2109.wav	"Yankee One, this is control. Proceed to position. Alpha Two. Over"
2110.wav	"Yankee One, this is control. Proceed to position Bravo Three. Over"
2111.wav	"Yankee One, this is control. Proceed to position Charlie Four. Over"
2112.wav	"Yankee One, this is control. Proceed to position Delta Five. Over"
2113.wav	"Yankee One, this is control. Proceed to position Echo Six. Over"
2114.wav	"Yankee One, this is control. Proceed to position Foxtrot Seven. Over"
2115.wav	"Yankee One, this is control. Proceed to position Golf Eight. Over"
2116.wav	"Yankee One, this is control. Proceed to position Hotel One. Over"
2117.wav	"Yankee One, this is control. Proceed to position Alpha Three. Over"
2118.wav	"Yankee One, this is control. Proceed to position Bravo Four. Over"
2119.wav	"Yankee One, this is control. Proceed to position Charlie Five. Over"
2120.wav	"Yankee One, this is control. Proceed to position Delta Six. Over"
2121.wav	"Yankee One, this is control. Proceed to position Echo Seven. Over"
2122.wav	"Yankee One, this is control. Proceed to position Foxtrot Eight. Over"
2123.wav	"Yankee One, this is control. Proceed to position Golf One. Over"
2124.wav	"Yankee One, this is control. Proceed to position Hotel Two. Over"
2125.wav	"Yankee One, this is control. Proceed to position Alpha Four. Over"
2126.wav	"Yankee One, this is control. Proceed to position Bravo Five. Over"
2127.wav	"Yankee One, this is control. Proceed to position Charlie Six. Over"
2128.wav	"Yankee One, this is control. Proceed to position Delta Seven. Over"
2129.wav	"Yankee One, this is control. Proceed to position Echo Eight. Over"
2130.wav	"Yankee One, this is control. Proceed to position Foxtrot One. Over"

Speaker One (Control)

Distracter Messages (2 source trials)

File	Message
2131.wav	"Zulu One, this is control. New objective, proceed to position Alpha One. Over"
2132.wav	"Zulu One, this is control. New objective, proceed to position Bravo Two. Over"
2133.wav	"Zulu One, this is control. New objective, proceed to position Charlie Three. Over"
2134.wav	"Zulu One, this is control. New objective, proceed to position Delta Four. Over"
2135.wav	"Zulu One, this is control. New objective, proceed to position Echo Five. Over"
2136.wav	"Zulu One, this is control. New objective, proceed to position Foxtrot Six. Over"
2137.wav	"Zulu One, this is control. New objective, proceed to position Golf Seven. Over"
2138.wav	"Zulu One, this is control. New objective, proceed to position. Hotel Eight. Over"
2139.wav	"Zulu One, this is control. New objective, proceed to position. Alpha Two. Over"
2140.wav	"Zulu One, this is control. New objective, proceed to position Bravo Three. Over"
2141.wav	"Zulu One, this is control. New objective, proceed to position Charlie Four. Over"
2142.wav	"Zulu One, this is control. New objective, proceed to position Delta Five. Over"
2143.wav	"Zulu One, this is control. New objective, proceed to position Echo Six. Over"
2144.wav	"Zulu One, this is control. New objective, proceed to position Foxtrot Seven. Over"
2145.wav	"Zulu One, this is control. New objective, proceed to position Golf Eight. Over"
2146.wav	"Zulu One, this is control. New objective, proceed to position Hotel One. Over"
2147.wav	"Zulu One, this is control. New objective, proceed to position Alpha Three. Over"
2148.wav	"Zulu One, this is control. New objective, proceed to position Bravo Four. Over"
2149.wav	"Zulu One, this is control. New objective, proceed to position Charlie Five. Over"
2150.wav	"Zulu One, this is control. New objective, proceed to position Delta Six. Over"

File	Message
2151.wav	"Zulu One, this is control. New objective, proceed to position Echo Seven. Over"
2152.wav	"Zulu One, this is control. New objective, proceed to position Foxtrot Eight. Over"
2153.wav	"Zulu One, this is control. New objective, proceed to position Golf One. Over"
2154.wav	"Zulu One, this is control. New objective, proceed to position Hotel Two. Over"
2155.wav	"Zulu One, this is control. New objective, proceed to position Alpha Four. Over"
2156.wav	"Zulu One, this is control. New objective, proceed to position Bravo Five. Over"
2157.wav	"Zulu One, this is control. New objective, proceed to position Charlie Six. Over"
2158.wav	"Zulu One, this is control. New objective, proceed to position Delta Seven. Over"
2159.wav	"Zulu One, this is control. New objective, proceed to position Echo Eight. Over"
2160.wav	"Zulu One, this is control. New objective, proceed to position Foxtrot One. Over"

Speaker One (Control)

Target Messages (4 source trials)

File	Message
4101.wav	"Yankee One, this is control. Proceed to position Alpha Five. Over"
4102.wav	"Yankee One, this is control. Proceed to position Bravo Six. Over"
4103.wav	"Yankee One, this is control. Proceed to position Charlie Seven. Over"
4104.wav	"Yankee One, this is control. Proceed to position Delta Eight. Over"
4105.wav	"Yankee One, this is control. Proceed to position Echo One. Over"
4106.wav	"Yankee One, this is control. Proceed to position Foxtrot Two. Over"
4107.wav	"Yankee One, this is control. Proceed to position Golf Three. Over"
4108.wav	"Yankee One, this is control. Proceed to position Hotel Four. Over"
4109.wav	"Yankee One, this is control. Proceed to position Alpha Six. Over"
4110.wav	"Yankee One, this is control. Proceed to position Bravo Seven. Over"
4111.wav	"Yankee One, this is control. Proceed to position Charlie Eight. Over"
4112.wav	"Yankee One, this is control. Proceed to position Delta One. Over"
4113.wav	"Yankee One, this is control. Proceed to position Echo Two. Over"
4114.wav	"Yankee One, this is control. Proceed to position Foxtrot Three. Over"
4115.wav	"Yankee One, this is control. Proceed to position Golf Four. Over"

Speaker One (Control)

Distracter Messages (4 source trials)

File	Message
4116.wav	"Zulu One, this is control. Investigate possible hostile at position Alpha One. Over"
4117.wav	"Zulu One, this is control. Investigate possible hostile at position Bravo Two. Over"
4118.wav	"Zulu One, this is control. Investigate possible hostile at position Charlie Three. Over"
4119.wav	"Zulu One, this is control. Investigate possible hostile at position Delta Four. Over"
4120.wav	"Zulu One, this is control. Investigate possible hostile at position Echo Five. Over"
4121.wav	"Zulu One, this is control. Investigate possible hostile at position Foxtrot Six. Over"
4122.wav	"Zulu One, this is control. Investigate possible hostile at position Golf Seven. Over"
4123.wav	"Zulu One, this is control. Investigate possible hostile at position Hotel Eight. Over"
4124.wav	"Zulu One, this is control. Investigate possible hostile at position Alpha Two. Over"
4125.wav	"Zulu One, this is control. Investigate possible hostile at position Bravo Three. Over"
4126.wav	"Zulu One, this is control. Investigate possible hostile at position Charlie Four. Over"
4127.wav	"Zulu One, this is control. Investigate possible hostile at position Delta Five. Over"
4128.wav	"Zulu One, this is control. Investigate possible hostile at position Echo Six. Over"
4129.wav	"Zulu One, this is control. Investigate possible hostile at position Foxtrot Seven. Over"
4130.wav	"Zulu One, this is control. Investigate possible hostile at position Golf Eight. Over"
4131.wav	"Zulu One, this is control. Investigate possible hostile at position Hotel One. Over"
4132.wav	"Zulu One, this is control. Investigate possible hostile at position Alpha Three. Over"
4133.wav	"Zulu One, this is control. Investigate possible hostile at position Bravo Four. Over"
4134.wav	"Zulu One, this is control. Investigate possible hostile at position Charlie Five. Over"
4135.wav	"Zulu One, this is control. Investigate possible hostile at position Delta Six Over"

File	Message
4136.wav	"Zulu One, this is control. Investigate possible hostile at position Echo Seven. Over"
4137.wav	"Zulu One, this is control. Investigate possible hostile at position Foxtrot Eight. Over"
4138.wav	"Zulu One, this is control. Investigate possible hostile at position Golf One. Over"
4139.wav	"Zulu One, this is control. Investigate possible hostile at position Hotel Two. Over"
4140.wav	"Zulu One, this is control. Investigate possible hostile at position Alpha Four. Over"
4141.wav	"Zulu One, this is control. Investigate possible hostile at position Bravo Five. Over"
4142.wav	"Zulu One, this is control. Investigate possible hostile at position Charlie Six. Over"
4143.wav	"Zulu One, this is control. Investigate possible hostile at position Delta Seven. Over"
4144.wav	"Zulu One, this is control. Investigate possible hostile at position Echo Eight. Over"
4145.wav	"Zulu One, this is control. Investigate possible hostile at position Foxtrot One. Over"
4146.wav	"Zulu One, this is control. Investigate possible hostile at position Golf Two. Over"
4147.wav	"Zulu One, this is control. Investigate possible hostile at position Hotel Three. Over"
4148.wav	"Zulu One, this is control. Investigate possible hostile at position Alpha Five. Over"
4149.wav	"Zulu One, this is control. Investigate possible hostile at position Bravo Six. Over"
4150.wav	"Zulu One, this is control. Investigate possible hostile at position Charlie Seven . Over"
4151.wav	"Zulu One, this is control. Investigate possible hostile at position Delta Eight. Over"
4152.wav	"Zulu One, this is control. Investigate possible hostile at position Echo One. Over"
4153.wav	"Zulu One, this is control. Investigate possible hostile at position Foxtrot Two. Over"
4154.wav	"Zulu One, this is control. Investigate possible hostile at position Golf Three. Over"
4155.wav	"Zulu One, this is control. Investigate possible hostile at position Hotel Four. Over"
4156.wav	"Zulu One, this is control. Investigate possible hostile at position Alpha Six. Over"
4157.wav	"Zulu One, this is control. Investigate possible hostile at position Bravo Seven. Over"

4158.wav	"Zulu One, this is control. Investigate possible hostile at position Charlie Eight. Over"
4159.wav	"Zulu One, this is control. Investigate possible hostile at position Delta One. Over"
4160.wav	"Zulu One, this is control. Investigate possible hostile at position Echo Two. Over"

Speaker Two (Zulu One)

Target Messages (2 source trials)

File	Message
2201.wav	"Yankee One, this is Zulu One. Request assistance at Alpha One. Over"
2202.wav	"Yankee One, this is Zulu One. Request assistance at Bravo Two. Over"
2203.wav	"Yankee One, this is Zulu One. Request assistance at Charlie Three. Over"
2204.wav	"Yankee One, this is Zulu One. Request assistance at Delta Four. Over"
2205.wav	"Yankee One, this is Zulu One. Request assistance at Echo Five. Over"
2206.wav	"Yankee One, this is Zulu One. Request assistance at Foxtrot Six. Over"
2207.wav	"Yankee One, this is Zulu One. Request assistance at Golf Seven. Over"
2208.wav	"Yankee One, this is Zulu One. Request assistance at Hotel Eight. Over"
2209.wav	"Yankee One, this is Zulu One. Request assistance at Alpha Two. Over"
2210.wav	"Yankee One, this is Zulu One. Request assistance at Bravo Three. Over"
2211.wav	"Yankee One, this is Zulu One. Request assistance at Charlie Four. Over"
2212.wav	"Yankee One, this is Zulu One. Request assistance at Delta Five. Over"
2213.wav	"Yankee One, this is Zulu One. Request assistance at Echo Six. Over"
2214.wav	"Yankee One, this is Zulu One. Request assistance at Foxtrot Seven. Over"
2215.wav	"Yankee One, this is Zulu One. Request assistance at Golf Eight. Over"
2216.wav	"Yankee One, this is Zulu One. Request assistance at Hotel One. Over"
2217.wav	"Yankee One, this is Zulu One. Request assistance at Alpha Three. Over"
2218.wav	"Yankee One, this is Zulu One. Request assistance at Bravo Four. Over"
2219.wav	"Yankee One, this is Zulu One. Request assistance at Charlie Five. Over"
2220.wav	"Yankee One, this is Zulu One. Request assistance at Delta Six. Over"
2221.wav	"Yankee One, this is Zulu One. Request assistance at Echo Seven. Over"
2222.wav	"Yankee One, this is Zulu One. Request assistance at Foxtrot Eight. Over"
2223.wav	"Yankee One, this is Zulu One. Request assistance at Golf One. Over"
2224.wav	"Yankee One, this is Zulu One. Request assistance at Hotel Two. Over"
2225.wav	"Yankee One, this is Zulu One. Request assistance at Alpha Four. Over"
2226.wav	"Yankee One, this is Zulu One. Request assistance at Bravo Five. Over"
2227.wav	"Yankee One, this is Zulu One. Request assistance at Charlie Six. Over"
2228.wav	"Yankee One, this is Zulu One. Request assistance at Delta Seven. Over"
2229.wav	"Yankee One, this is Zulu One. Request assistance at Echo Eight. Over"
2230.wav	"Yankee One, this is Zulu One. Request assistance at Foxtrot One. Over"

Speaker Two (Zulu One)

Distracter Messages (2 source trials)

File	Message
2231.wav	"Control, this is Zulu One. Objective complete. We are moving to Alpha One. Over"
2232.wav	"Control, this is Zulu One. Objective complete. We are moving to Bravo Two. Over"
2233.wav	"Control, this is Zulu One. Objective complete. We are moving to Charlie Three. Over"
2234.wav	"Control, this is Zulu One. Objective complete. We are moving to Delta Four. Over"
2235.wav	"Control, this is Zulu One. Objective complete. We are moving to Echo Five. Over"
2236.wav	"Control, this is Zulu One. Objective complete. We are moving to Foxtrot Six. Over"
2237.wav	"Control, this is Zulu One. Objective complete. We are moving to Golf Seven. Over"
2238.wav	"Control, this is Zulu One. Objective complete. We are moving to Hotel Eight. Over"
2239.wav	"Control, this is Zulu One. Objective complete. We are moving to Alpha Two. Over"
2240.wav	"Control, this is Zulu One. Objective complete. We are moving to Bravo Three. Over"
2241.wav	"Control, this is Zulu One. Objective complete. We are moving to Charlie Four. Over"
2242.wav	"Control, this is Zulu One. Objective complete. We are moving to Delta Five. Over"
2243.wav	"Control, this is Zulu One. Objective complete. We are moving to Echo Six. Over"
2244.wav	"Control, this is Zulu One. Objective complete. We are moving to Foxtrot Seven. Over"
2245.wav	"Control, this is Zulu One. Objective complete. We are moving to Golf Eight. Over"
2246.wav	"Control, this is Zulu One. Objective complete. We are moving to Hotel One. Over"
2247.wav	"Control, this is Zulu One. Objective complete. We are moving to Alpha Three. Over"
2248.wav	"Control, this is Zulu One. Objective complete. We are moving to Bravo Four. Over"
2249.wav	"Control, this is Zulu One. Objective complete. We are moving to Charlie Five. Over"
2250.wav	"Control, this is Zulu One. Objective complete. We are moving to Delta Six. Over"

File	Message
2251.wav	"Control, this is Zulu One. Objective complete. We are moving to Echo Seven. Over"
2252.wav	"Control, this is Zulu One. Objective complete. We are moving to Foxtrot Eight. Over"
2253.wav	"Control, this is Zulu One. Objective complete. We are moving to Golf One. Over"
2254.wav	"Control, this is Zulu One. Objective complete. We are moving to Hotel Two. Over"
2255.wav	"Control, this is Zulu One. Objective complete. We are moving to Alpha Four. Over"
2256.wav	"Control, this is Zulu One. Objective complete. We are moving to Bravo Five. Over"
2257.wav	"Control, this is Zulu One. Objective complete. We are moving to Charlie Six. Over"
2258.wav	"Control, this is Zulu One. Objective complete. We are moving to Delta Seven. Over"
2259.wav	"Control, this is Zulu One. Objective complete. We are moving to Echo Eight. Over"
2260.wav	"Control, this is Zulu One. Objective complete. We are moving to Foxtrot One. Over"

Speaker Two (Zulu One)

Target Messages (4 source trials)

File	Message
4201.wav	"Yankee One, this is Zulu One. Request assistance at Alpha Five. Over"
4202.wav	"Yankee One, this is Zulu One. Request assistance at Bravo Six. Over"
4203.wav	"Yankee One, this is Zulu One. Request assistance at Charlie Seven. Over"
4204.wav	"Yankee One, this is Zulu One. Request assistance at Delta Eight. Over"
4205.wav	"Yankee One, this is Zulu One. Request assistance at Echo One. Over"
4206.wav	"Yankee One, this is Zulu One. Request assistance at Foxtrot Two. Over"
4207.wav	"Yankee One, this is Zulu One. Request assistance at Golf Three. Over"
4208.wav	"Yankee One, this is Zulu One. Request assistance at Hotel Four. Over"
4209.wav	"Yankee One, this is Zulu One. Request assistance at Alpha Six. Over"
4210.wav	"Yankee One, this is Zulu One. Request assistance at Bravo Seven. Over"
4211.wav	"Yankee One, this is Zulu One. Request assistance at Charlie Eight. Over"
4212.wav	"Yankee One, this is Zulu One. Request assistance at Delta One. Over"
4213.wav	"Yankee One, this is Zulu One. Request assistance at Echo Two. Over"
4214.wav	"Yankee One, this is Zulu One. Request assistance at Foxtrot Three. Over"

File	Message
4215.wav	"Yankee One, this is Zulu One. Request assistance at Golf Four. Over"

Speaker Two (Zulu One)

Distracter Messages (4 source trials)

File	Message
4216.wav	"Control, this is Zulu One. Objective Complete. Moving to position Alpha One. Over"
4217.wav	"Control, this is Zulu One. Objective Complete. Moving to position Bravo Two. Over"
4218.wav	"Control, this is Zulu One. Objective Complete. Moving to position Charlie Three. Over"
4219.wav	"Control, this is Zulu One. Objective Complete. Moving to position Delta Four. Over"
4220.wav	"Control, this is Zulu One. Objective Complete. Moving to position Echo Five. Over"
4221.wav	"Control, this is Zulu One. Objective Complete. Moving to position Foxtrot Six. Over"
4222.wav	"Control, this is Zulu One. Objective Complete. Moving to position Golf Seven. Over"
4223.wav	"Control, this is Zulu One. Objective Complete. Moving to position Hotel Eight. Over"
4224.wav	"Control, this is Zulu One. Objective Complete. Moving to position Alpha Two. Over"
4225.wav	"Control, this is Zulu One. Objective Complete. Moving to position Bravo Three. Over"
4226.wav	"Control, this is Zulu One. Objective Complete. Moving to position Charlie Four. Over"
4227.wav	"Control, this is Zulu One. Objective Complete. Moving to position Delta Five. Over"
4228.wav	"Control, this is Zulu One. Objective Complete. Moving to position Echo Six. Over"
4229.wav	"Control, this is Zulu One. Objective Complete. Moving to position Foxtrot Seven. Over"
4230.wav	"Control, this is Zulu One. Objective Complete. Moving to position Golf Eight. Over"
4231.wav	"Control, this is Zulu One. Objective Complete. Moving to position Hotel One. Over"
4232.wav	"Control, this is Zulu One. Objective Complete. Moving to position Alpha Three. Over"
4233.wav	"Control, this is Zulu One. Objective Complete. Moving to position Bravo Four. Over"

File	Message
4234.wav	"Control, this is Zulu One. Objective Complete. Moving to position Charlie Five. Over"
4235.wav	"Control, this is Zulu One. Objective Complete. Moving to position Delta Six Over"
4236.wav	"Control, this is Zulu One. Objective Complete. Moving to position Echo Seven. Over"
4237.wav	"Control, this is Zulu One. Objective Complete. Moving to position Foxtrot Eight. Over"
4238.wav	"Control, this is Zulu One. Objective Complete. Moving to position Golf One. Over"
4239.wav	"Control, this is Zulu One. Objective Complete. Moving to position Hotel Two. Over"
4240.wav	"Control, this is Zulu One. Objective Complete. Moving to position Alpha Four. Over"
4241.wav	"Control, this is Zulu One. Objective Complete. Moving to position Bravo Five. Over"
4242.wav	"Control, this is Zulu One. Objective Complete. Moving to position Charlie Six. Over"
4243.wav	"Control, this is Zulu One. Objective Complete. Moving to position Delta Seven. Over"
4244.wav	"Control, this is Zulu One. Objective Complete. Moving to position Echo Eight. Over"
4245.wav	"Control, this is Zulu One. Objective Complete. Moving to position Foxtrot One. Over"
4246.wav	"Control, this is Zulu One. Objective Complete. Moving to position Golf Two. Over"
4247.wav	"Control, this is Zulu One. Objective Complete. Moving to position Hotel Three. Over"
4248.wav	"Control, this is Zulu One. Objective Complete. Moving to position Alpha Five. Over"
4249.wav	"Control, this is Zulu One. Objective Complete. Moving to position Bravo Six. Over"
4250.wav	"Control, this is Zulu One. Objective Complete. Moving to position Charlie Seven . Over"
4251.wav	"Control, this is Zulu One. Objective Complete. Moving to position Delta Eight. Over"
4252.wav	"Control, this is Zulu One. Objective Complete. Moving to position Echo One. Over"
4253.wav	"Control, this is Zulu One. Objective Complete. Moving to position Foxtrot Two. Over"
4254.wav	"Control, this is Zulu One. Objective Complete. Moving to position Golf Three. Over"
4255.wav	"Control, this is Zulu One. Objective Complete. Moving to position Hotel Four. Over"

File	Message
4256.wav	"Control, this is Zulu One. Objective Complete. Moving to position Alpha Six. Over"
4257.wav	"Control, this is Zulu One. Objective Complete. Moving to position Bravo Seven. Over"
4258.wav	"Control, this is Zulu One. Objective Complete. Moving to position Charlie Eight. Over"
4259.wav	"Control, this is Zulu One. Objective Complete. Moving to position Delta One. Over"
4260.wav	"Control, this is Zulu One. Objective Complete. Moving to position Echo Two. Over"

Speaker Three (Yankee Two)

Target Messages (4 source trials)

File	Message
4301.wav	"Yankee One, this is Yankee Two. Possible hostile at Alpha One. Over"
4302.wav	"Yankee One, this is Yankee Two. Possible hostile at Bravo Two. Over"
4303.wav	"Yankee One, this is Yankee Two. Possible hostile at Charlie Three. Over"
4304.wav	"Yankee One, this is Yankee Two. Possible hostile at Delta Four. Over"
4305.wav	"Yankee One, this is Yankee Two. Possible hostile at Echo Five. Over"
4306.wav	"Yankee One, this is Yankee Two. Possible hostile at Foxtrot Six. Over"
4307.wav	"Yankee One, this is Yankee Two. Possible hostile at Golf Seven. Over"
4308.wav	"Yankee One, this is Yankee Two. Possible hostile at Hotel Eight. Over"
4309.wav	"Yankee One, this is Yankee Two. Possible hostile at Alpha Two. Over"
4310.wav	"Yankee One, this is Yankee Two. Possible hostile at Bravo Three. Over"
4311.wav	"Yankee One, this is Yankee Two. Possible hostile at Charlie Four. Over"
4312.wav	"Yankee One, this is Yankee Two. Possible hostile at Delta Five. Over"
4313.wav	"Yankee One, this is Yankee Two. Possible hostile at Echo Six. Over"
4314.wav	"Yankee One, this is Yankee Two. Possible hostile at Foxtrot Seven. Over"
4315.wav	"Yankee One, this is Yankee Two. Possible hostile at Golf Eight. Over"

Speaker Three (Yankee Two)

Distracter Messages (4 source trials)

File	Message
4316.wav	"Yankee Three, this is Yankee Two. I am closing in on the target at Alpha One. Over"
4317.wav	"Yankee Three, this is Yankee Two. I am closing in on the target at Bravo Two. Over"
4318.wav	"Yankee Three, this is Yankee Two. I am closing in on the target at Charlie Three. Over"

File	Message
4319.wav	"Yankee Three, this is Yankee Two. I am closing in on the target at Delta Four. Over"
4320.wav	"Yankee Three, this is Yankee Two. I am closing in on the target at Echo Five. Over"
4321.wav	"Yankee Three, this is Yankee Two. I am closing in on the target at Foxtrot Six. Over"
4322.wav	"Yankee Three, this is Yankee Two. I am closing in on the target at Golf Seven. Over"
4323.wav	"Yankee Three, this is Yankee Two. I am closing in on the target at Hotel Eight. Over"
4324.wav	"Yankee Three, this is Yankee Two. I am closing in on the target at Alpha Two. Over"
4325.wav	"Yankee Three, this is Yankee Two. I am closing in on the target at Bravo Three. Over"
4326.wav	"Yankee Three, this is Yankee Two. I am closing in on the target at Charlie Four. Over"
4327.wav	"Yankee Three, this is Yankee Two. I am closing in on the target at Delta Five. Over"
4328.wav	"Yankee Three, this is Yankee Two. I am closing in on the target at Echo Six. Over"
4329.wav	"Yankee Three, this is Yankee Two. I am closing in on the target at Foxtrot Seven. Over"
4330.wav	"Yankee Three, this is Yankee Two. I am closing in on the target at Golf Eight. Over"
4331.wav	"Yankee Three, this is Yankee Two. I am closing in on the target at Hotel One. Over"
4332.wav	"Yankee Three, this is Yankee Two. I am closing in on the target at Alpha Three. Over"
4333.wav	"Yankee Three, this is Yankee Two. I am closing in on the target at Bravo Four. Over"
4334.wav	"Yankee Three, this is Yankee Two. I am closing in on the target at Charlie Five. Over"
4335.wav	"Yankee Three, this is Yankee Two. I am closing in on the target at Delta Six Over"
4336.wav	"Yankee Three, this is Yankee Two. I am closing in on the target at Echo Seven. Over"
4337.wav	"Yankee Three, this is Yankee Two. I am closing in on the target at Foxtrot Eight. Over"
4338.wav	"Yankee Three, this is Yankee Two. I am closing in on the target at Golf One. Over"
4339.wav	"Yankee Three, this is Yankee Two. I am closing in on the target at Hotel Two. Over"
4340.wav	"Yankee Three, this is Yankee Two. I am closing in on the target at Alpha Four. Over"

4341.wav	"Yankee Three, this is Yankee Two. I am closing in on the target at Bravo Five. Over"

File	Message
4342.wav	"Yankee Three, this is Yankee Two. I am closing in on the target at Charlie Six. Over"
4343.wav	"Yankee Three, this is Yankee Two. I am closing in on the target at Delta Seven. Over"
4344.wav	"Yankee Three, this is Yankee Two. I am closing in on the target at Echo Eight. Over"
4345.wav	"Yankee Three, this is Yankee Two. I am closing in on the target at Foxtrot One. Over"
4346.wav	"Yankee Three, this is Yankee Two. I am closing in on the target at Golf Two. Over"
4347.wav	"Yankee Three, this is Yankee Two. I am closing in on the target at Hotel Three. Over"
4348.wav	"Yankee Three, this is Yankee Two. I am closing in on the target at Alpha Five. Over"
4349.wav	"Yankee Three, this is Yankee Two. I am closing in on the target at Bravo Six. Over"
4350.wav	"Yankee Three, this is Yankee Two. I am closing in on the target at Charlie Seven . Over"
4351.wav	"Yankee Three, this is Yankee Two. I am closing in on the target at Delta Eight. Over"
4352.wav	"Yankee Three, this is Yankee Two. I am closing in on the target at Echo One. Over"
4353.wav	"Yankee Three, this is Yankee Two. I am closing in on the target at Foxtrot Two. Over"
4354.wav	"Yankee Three, this is Yankee Two. I am closing in on the target at Golf Three. Over"
4355.wav	"Yankee Three, this is Yankee Two. I am closing in on the target at Hotel Four. Over"
4356.wav	"Yankee Three, this is Yankee Two. I am closing in on the target at Alpha Six. Over"
4357.wav	"Yankee Three, this is Yankee Two. I am closing in on the target at Bravo Seven. Over"
4358.wav	"Yankee Three, this is Yankee Two. I am closing in on the target at Charlie Eight. Over"
4359.wav	"Yankee Three, this is Yankee Two. I am closing in on the target at Delta One. Over"
4360.wav	"Yankee Three, this is Yankee Two. I am closing in on the target at Echo Two. Over"

Speaker Four (Yankee Three)

Target Messages (4 source trials)

File	Message
4401.wav	"Yankee One, this is Yankee Three. Attacking target at Alpha Five. Over"
4402.wav	"Yankee One, this is Yankee Three. Attacking target at Bravo Six. Over"
4403.wav	"Yankee One, this is Yankee Three. Attacking target at Charlie Seven. Over"
4404.wav	"Yankee One, this is Yankee Three. Attacking target at Delta Eight. Over"
4405.wav	"Yankee One, this is Yankee Three. Attacking target at Echo One. Over"
4406.wav	"Yankee One, this is Yankee Three. Attacking target at Foxtrot Two. Over"
4407.wav	"Yankee One, this is Yankee Three. Attacking target at Golf Three. Over"
4408.wav	"Yankee One, this is Yankee Three. Attacking target at Hotel Four. Over"
4409.wav	"Yankee One, this is Yankee Three. Attacking target at Alpha Six. Over"
4410.wav	"Yankee One, this is Yankee Three. Attacking target at Bravo Seven. Over"
4411.wav	"Yankee One, this is Yankee Three. Attacking target at Charlie Eight. Over"
4412.wav	"Yankee One, this is Yankee Three. Attacking target at Delta One. Over"
4413.wav	"Yankee One, this is Yankee Three. Attacking target at Echo Two. Over"
4414.wav	"Yankee One, this is Yankee Three. Attacking target at Foxtrot Three. Over"
4415.wav	"Yankee One, this is Yankee Three. Attacking target at Golf Four. Over"

Speaker Four (Yankee Three)

Distracter Messages (4 source trials)

File	Message
4416.wav	"Yankee Two, this is Yankee Three. I have sighted another hostile at Alpha One. Over"
4417.wav	"Yankee Two, this is Yankee Three. I have sighted another hostile at Bravo Two. Over"

File	Message
4418.wav	"Yankee Two, this is Yankee Three. I have sighted another hostile at Charlie Three. Over"
4419.wav	"Yankee Two, this is Yankee Three. I have sighted another hostile at Delta Four. Over"
4420.wav	"Yankee Two, this is Yankee Three. I have sighted another hostile at Echo Five. Over"
4421.wav	"Yankee Two, this is Yankee Three. I have sighted another hostile at Foxtrot Six. Over"
4422.wav	"Yankee Two, this is Yankee Three. I have sighted another hostile at Golf Seven. Over"
4423.wav	"Yankee Two, this is Yankee Three. I have sighted another hostile at Hotel Eight. Over"
4424.wav	"Yankee Two, this is Yankee Three. I have sighted another hostile at Alpha Two. Over"
4425.wav	"Yankee Two, this is Yankee Three. I have sighted another hostile at Bravo Three. Over"
4426.wav	"Yankee Two, this is Yankee Three. I have sighted another hostile at Charlie Four. Over"
4427.wav	"Yankee Two, this is Yankee Three. I have sighted another hostile at Delta Five. Over"
4428.wav	"Yankee Two, this is Yankee Three. I have sighted another hostile at Echo Six. Over"
4429.wav	"Yankee Two, this is Yankee Three. I have sighted another hostile at Foxtrot Seven. Over"
4430.wav	"Yankee Two, this is Yankee Three. I have sighted another hostile at Golf Eight. Over"
4431.wav	"Yankee Two, this is Yankee Three. I have sighted another hostile at Hotel One. Over"
4432.wav	"Yankee Two, this is Yankee Three. I have sighted another hostile at Alpha Three. Over"
4433.wav	"Yankee Two, this is Yankee Three. I have sighted another hostile at Bravo Four. Over"
4434.wav	"Yankee Two, this is Yankee Three. I have sighted another hostile at Charlie Five. Over"
4435.wav	"Yankee Two, this is Yankee Three. I have sighted another hostile at Delta Six Over"
4436.wav	"Yankee Two, this is Yankee Three. I have sighted another hostile at Echo Seven. Over"
4437.wav	"Yankee Two, this is Yankee Three. I have sighted another hostile at Foxtrot Eight. Over"
4438.wav	"Yankee Two, this is Yankee Three. I have sighted another hostile at Golf One. Over"
4439.wav	"Yankee Two, this is Yankee Three. I have sighted another hostile at Hotel Two. Over"

File	Message
4440.wav	"Yankee Two, this is Yankee Three. I have sighted another hostile at Alpha Four. Over"
4441.wav	"Yankee Two, this is Yankee Three. I have sighted another hostile at Bravo Five. Over"
4442.wav	"Yankee Two, this is Yankee Three. I have sighted another hostile at Charlie Six. Over"
4443.wav	"Yankee Two, this is Yankee Three. I have sighted another hostile at Delta Seven. Over"
4444.wav	"Yankee Two, this is Yankee Three. I have sighted another hostile at Echo Eight. Over"
4445.wav	"Yankee Two, this is Yankee Three. I have sighted another hostile at Foxtrot One. Over"
4446.wav	"Yankee Two, this is Yankee Three. I have sighted another hostile at Golf Two. Over"
4447.wav	"Yankee Two, this is Yankee Three. I have sighted another hostile at Hotel Three. Over"
4448.wav	"Yankee Two, this is Yankee Three. I have sighted another hostile at Alpha Five. Over"
4449.wav	"Yankee Two, this is Yankee Three. I have sighted another hostile at Bravo Six. Over"
4450.wav	"Yankee Two, this is Yankee Three. I have sighted another hostile at Charlie Seven . Over"
4451.wav	"Yankee Two, this is Yankee Three. I have sighted another hostile at Delta Eight. Over"
4452.wav	"Yankee Two, this is Yankee Three. I have sighted another hostile at Echo One. Over"
4453.wav	"Yankee Two, this is Yankee Three. I have sighted another hostile at Foxtrot Two. Over"
4454.wav	"Yankee Two, this is Yankee Three. I have sighted another hostile at Golf Three. Over"
4455.wav	"Yankee Two, this is Yankee Three. I have sighted another hostile at Hotel Four. Over"
4456.wav	"Yankee Two, this is Yankee Three. I have sighted another hostile at Alpha Six. Over"
4457.wav	"Yankee Two, this is Yankee Three. I have sighted another hostile at Bravo Seven. Over"
4458.wav	"Yankee Two, this is Yankee Three. I have sighted another hostile at Charlie Eight. Over"
4459.wav	"Yankee Two, this is Yankee Three. I have sighted another hostile at Delta One. Over"
4460.wav	"Yankee Two, this is Yankee Three. I have sighted another hostile at Echo Two. Over"

APPENDIX B. PILOT STUDY SCRIPT GENERATION

The following code was used to construct experimental trials.

```
import java.util.*;

public class ScriptMaker1{

   public static void main(String args[]){

      //target messages for 2 and 4 source experiments,
      //ex. v21 = 2 sources, voice 1

      ArrayList v21Target = new ArrayList();
      ArrayList v22Target = new ArrayList();
      ArrayList v41Target = new ArrayList();
      ArrayList v42Target = new ArrayList();
      ArrayList v43Target = new ArrayList();
      ArrayList v44Target = new ArrayList();

      //distractor messages for 2 and 4 source experiments
      ArrayList v21Distractors = new ArrayList();
      ArrayList v22Distractors = new ArrayList();
      ArrayList v41Distractors = new ArrayList();
      ArrayList v42Distractors = new ArrayList();
      ArrayList v43Distractors = new ArrayList();
      ArrayList v44Distractors = new ArrayList();

      ArrayList twoVoice = new ArrayList();
      ArrayList fourVoice = new ArrayList();
      Integer target = new Integer(0);
      int random;

      //populates arrays with message file identifiers for 2 source experiment
      for (int i=2101; i <= 2130; i++){
         v21Target.add(new Integer(i));
      }

      for (int i=2201; i <= 2230; i++){
         v22Target.add(new Integer(i));
      }

      for (int i=2131; i <= 2160; i++){
         v21Distractors.add(new Integer(i));
      }

      for (int i=2231; i <= 2260; i++){
         v22Distractors.add(new Integer(i));
      }

      //populates arrays with message file identifiers for 4 source experiment
      for (int i=4101; i <= 4115; i++){
         v41Target.add(new Integer(i));
      }

      for (int i=4201; i <= 4215; i++){
         v42Target.add(new Integer(i));
      }

      for (int i=4301; i <= 4315; i++){
         v43Target.add(new Integer(i));
      }

      for (int i=4401; i <= 4415; i++){
         v44Target.add(new Integer(i));
      }
```

```
for (int i=4116; i <= 4160; i++){
   v41Distractors.add(new Integer(i));
}

for (int i=4216; i <= 4260; i++){
   v42Distractors.add(new Integer(i));
}

for (int i=4316; i <= 4360; i++){
   v43Distractors.add(new Integer(i));
}

for (int i=4416; i <= 4460; i++){
   v44Distractors.add(new Integer(i));
}

//Experiment with two sources
for (int i =0; i<30; i++){
   twoVoice.add(new Integer(1));
   twoVoice.add(new Integer(2));
}
while(twoVoice.size()>0){
   random = (int)(twoVoice.size()*Math.random());
   target = (Integer)twoVoice.remove(random);
   if (target.intValue() == 1){
      random = (int)(v21Target.size()*Math.random());
      target = (Integer)v21Target.remove(random);
      System.out.print(target.intValue()+":");
      random = (int)(v22Distractors.size()*Math.random());
      target = (Integer)v22Distractors.remove(random);
      System.out.println(target.intValue());
   }
   else{
      random = (int)(v22Target.size()*Math.random());
      target = (Integer)v22Target.remove(random);
      System.out.print(target.intValue()+":");
      random = (int)(v21Distractors.size()*Math.random());
      target = (Integer)v21Distractors.remove(random);
      System.out.println(target.intValue());
   }
}

//Experiment with four sources
for (int i =0; i<15; i++){
   fourVoice.add(new Integer(1));
   fourVoice.add(new Integer(2));
   fourVoice.add(new Integer(3));
   fourVoice.add(new Integer(4));

}
while(fourVoice.size()>0){
   random = (int)(fourVoice.size()*Math.random());
   target = (Integer)fourVoice.remove(random);
   switch(target.intValue()){
      case 1:
         random = (int)(v41Target.size()*Math.random());
         target = (Integer)v41Target.remove(random);
         System.out.print(target.intValue()+":");
         random = (int)(v42Distractors.size()*Math.random());
         target = (Integer)v42Distractors.remove(random);
         System.out.print(target.intValue()+":");
         random = (int)(v43Distractors.size()*Math.random());
         target = (Integer)v43Distractors.remove(random);
         System.out.print(target.intValue()+":");
         random = (int)(v44Distractors.size()*Math.random());
         target = (Integer)v44Distractors.remove(random);
         System.out.println(target.intValue());
         break;

      case 2:
```

```
            random = (int)(v42Target.size()*Math.random());
            target = (Integer)v42Target.remove(random);
            System.out.print(target.intValue()+":");
            random = (int)(v41Distractors.size()*Math.random());
            target = (Integer)v41Distractors.remove(random);
            System.out.print(target.intValue()+":");
            random = (int)(v43Distractors.size()*Math.random());
            target = (Integer)v43Distractors.remove(random);
            System.out.print(target.intValue()+":");
            random = (int)(v44Distractors.size()*Math.random());
            target = (Integer)v44Distractors.remove(random);
            System.out.println(target.intValue());
            break;

         case 3:
            random = (int)(v43Target.size()*Math.random());
            target = (Integer)v43Target.remove(random);
            System.out.print(target.intValue()+":");
            random = (int)(v42Distractors.size()*Math.random());
            target = (Integer)v42Distractors.remove(random);
            System.out.print(target.intValue()+":");
            random = (int)(v41Distractors.size()*Math.random());
            target = (Integer)v41Distractors.remove(random);
            System.out.print(target.intValue()+":");
            random = (int)(v44Distractors.size()*Math.random());
            target = (Integer)v44Distractors.remove(random);
            System.out.println(target.intValue());
            break;

         default:
            random = (int)(v44Target.size()*Math.random());
            target = (Integer)v44Target.remove(random);
            System.out.print(target.intValue()+":");
            random = (int)(v42Distractors.size()*Math.random());
            target = (Integer)v42Distractors.remove(random);
            System.out.print(target.intValue()+":");
            random = (int)(v43Distractors.size()*Math.random());
            target = (Integer)v43Distractors.remove(random);
            System.out.print(target.intValue()+":");
            random = (int)(v41Distractors.size()*Math.random());
            target = (Integer)v41Distractors.remove(random);
            System.out.println(target.intValue());
            break;
      }
    }
  }
}
```

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APPENDIX C. PILOT STUDY SCRIPT

This appendix contains the ascii text output from the JAVA generator which has been reformatted in Microsoft Excel. Numbers refer to the wave file names found in Appendix A.

Part One (Two Voices)

Trial	Target	Distracter
1	2121	2243
2	2103	2231
3	2222	2134
4	2228	2156
5	2209	2146
6	2201	2152
7	2208	2131
8	2216	2135
9	2116	2257
10	2120	2244
11	2223	2159
12	2217	2144
13	2126	2245
14	2211	2147
15	2124	2232
16	2109	2250
17	2226	2154
18	2104	2255
19	2224	2157
20	2214	2155
21	2206	2145
22	2225	2136
23	2207	2142
24	2227	2153
25	2128	2251
26	2204	2137
27	2112	2238
28	2108	2239
29	2115	2252
30	2202	2150
31	2210	2132
32	2106	2240
33	2118	2259
34	2219	2158
35	2130	2253
36	2221	2133
37	2113	2246

38	2123	2256
39	2230	2149
40	2220	2151
41	2125	2234
42	2129	2247
43	2213	2160
44	2111	2242
45	2107	2235
46	2218	2143
47	2212	2138
48	2119	2237
49	2105	2248
50	2110	2236
51	2102	2233
52	2203	2139
53	2215	2140
54	2122	2260
55	2101	2241
56	2127	2249
57	2229	2141
58	2205	2148
59	2114	2254
60	2117	2258

Part Two (Four Voices)

Trial	Target	Distracter 1	Distracter 2	Distracter 3
61	4108	4217	4358	4416
62	4209	4119	4340	4421
63	4204	4157	4357	4451
64	4103	4253	4338	4457
65	4110	4246	4354	4442
66	4406	4216	4326	4127
67	4407	4228	4346	4137
68	4414	4218	4350	4139
69	4111	4260	4334	4435
70	4213	4131	4352	4431
71	4112	4257	4333	4439
72	4403	4241	4329	4133
73	4206	4123	4339	4459
74	4404	4256	4356	4156
75	4411	4238	4332	4145
76	4211	4129	4316	4438
77	4203	4124	4323	4452
78	4310	4233	4159	4427
79	4212	4121	4327	4440
80	4415	4254	4331	4130
81	4115	4255	4336	4429
82	4311	4220	4132	4454
83	4113	4224	4353	4424
84	4408	4243	4348	4149
85	4214	4116	4335	4437
86	4313	4236	4150	4422
87	4215	4154	4317	4453
88	4305	4230	4152	4423
89	4410	4242	4351	4142
90	4413	4252	4347	4147
91	4109	4232	4344	4444
92	4307	4222	4120	4436
93	4114	4227	4355	4447
94	4210	4146	4330	4419
95	4207	4125	4359	4443
96	4202	4153	4337	4450
97	4104	4249	4325	4455
98	4312	4219	4148	4418
99	4107	4251	4342	4433
100	4308	4244	4155	4430
101	4304	4258	4118	4458
102	4409	4237	4349	4140
103	4101	4229	4321	4428
104	4106	4259	4319	4441
105	4315	4248	4138	4432

106	4208	4134	4322	4420
107	4309	4231	4128	4426
108	4314	4226	4141	4449
109	4301	4235	4143	4434
110	4205	4136	4324	4446
111	4405	4223	4318	4135
112	4201	4158	4343	4445
113	4302	4221	4126	4417
114	4105	4250	4341	4448
115	4401	4247	4360	4144
116	4102	4239	4320	4460
117	4412	4245	4328	4160
118	4303	4234	4122	4456
119	4306	4240	4117	4425
120	4402	4225	4345	4151

APPENDIX D. PILOT STUDY INSTRUCTIONS

This experiment will attempt to capture the important elements of a task that requires simultaneous attention to multiple communications channels. Participants are placed in the role of a unit leader in a generic military environment (Yankee One). They are then asked to listen to messages from two subordinates (Yankee Two/Yankee Three), a peer (Zulu One), and a command entity (Control).

For each trial, participants are asked to listen to either two or four overlapping messages over headphones. They respond to the message that is addressed to them by making selections from drop-down lists in a data entry form. The purpose of the study is to determine whether a spatial auditory display increases message intelligibility (measured by response accuracy). Without the display, messages sound as if they are being delivered over normal stereo headphones. With spatial audio, the sounds should appear to originate from two or four separate locations around the listener.

Instructions: You will listen to 120 sets of overlapping messages. Each set will last approximately five seconds. Listen for your call- sign and attempt to focus on the corresponding message. You will be asked to respond to the message by identifying two elements.

1) Who was the **Speaker** that addressed you?

Voice One - **"Control"**
Voice Two - **"Zulu One"**
Voice Three - **"Yankee Two"**
Voice Four - **"Yankee Three"**

Note: During the first 60 trials you will only hear messages from Control and Zulu One.

2) Which **Coordinate Position** was referenced in the target message?

a) Y-Axis: alphabetical component
b) X-Axis: numeric component

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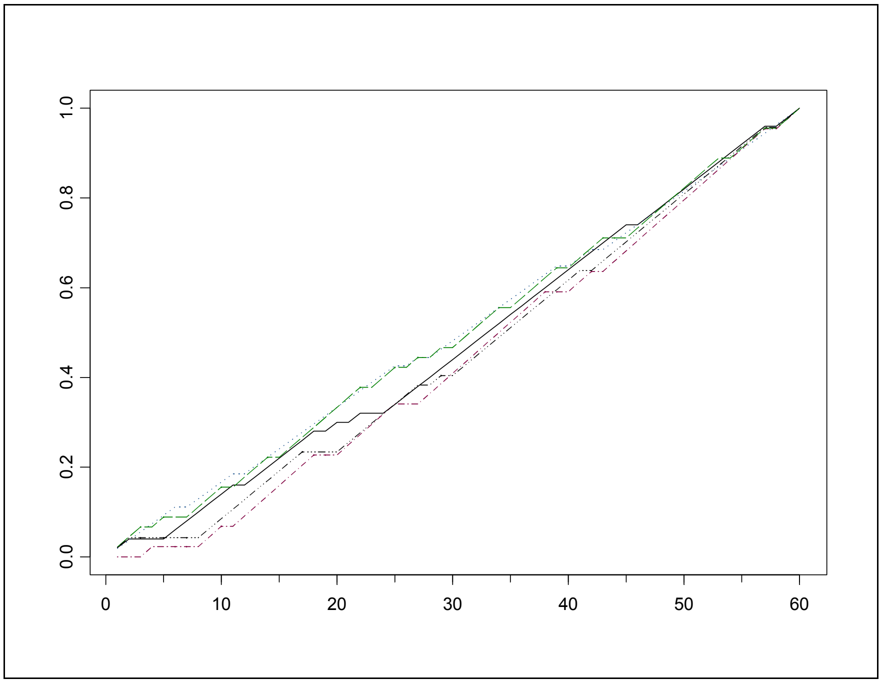
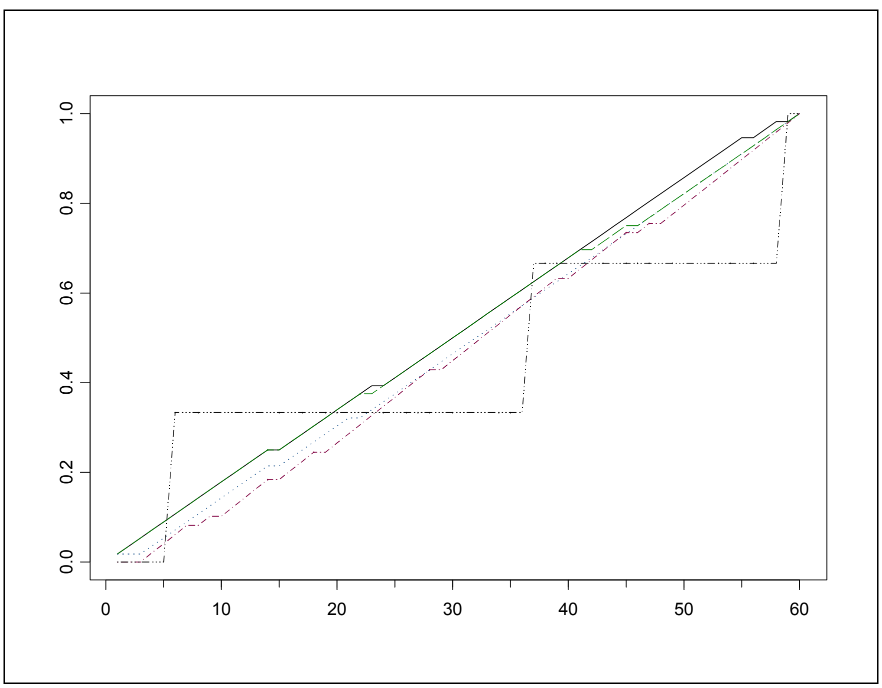
APPENDIX E.   TIME SERIES PLOTS

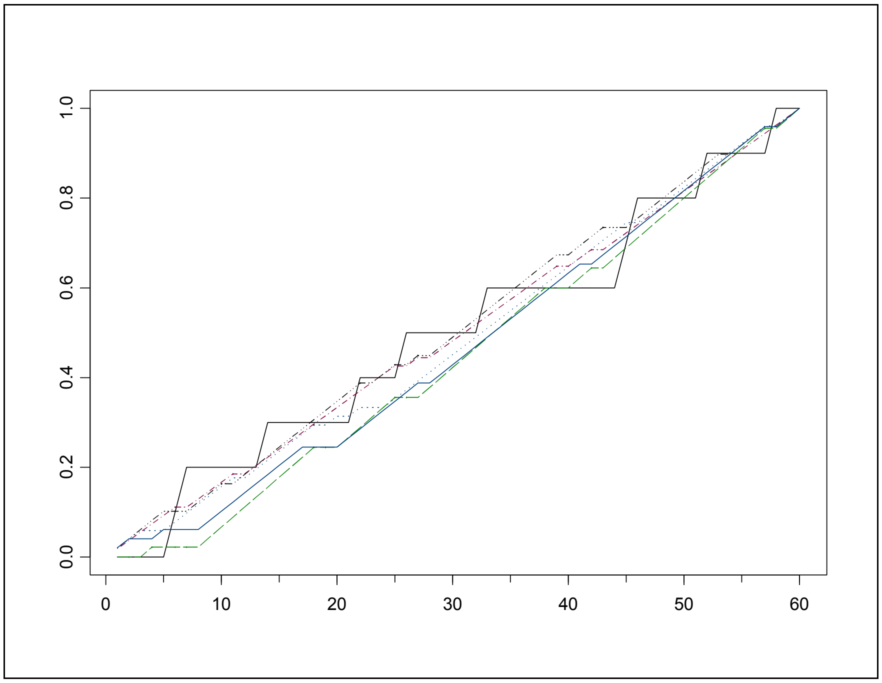
2 voices, non-spatialized, aggregate



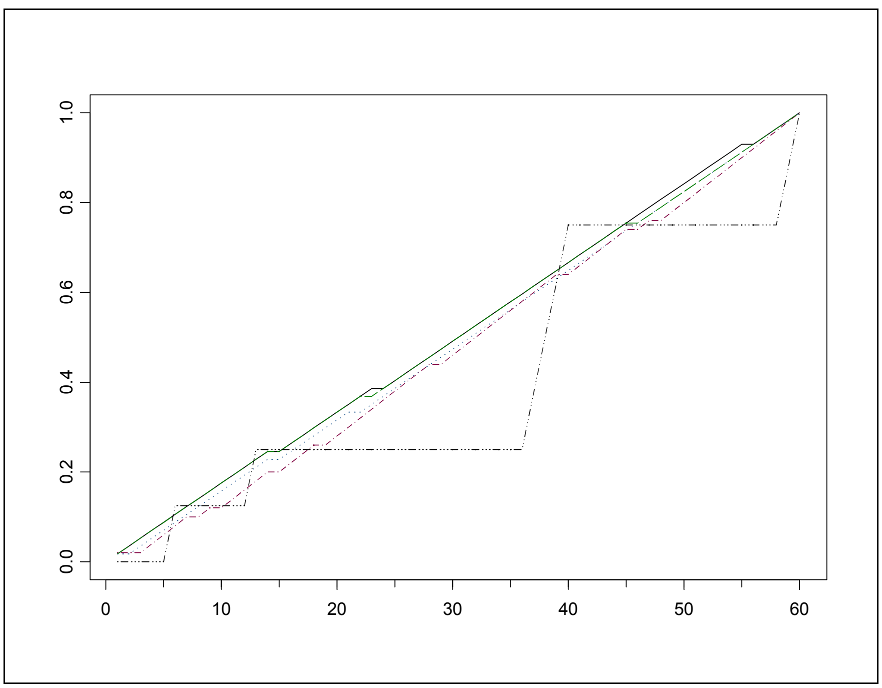
2 voice, spatialized, aggregate



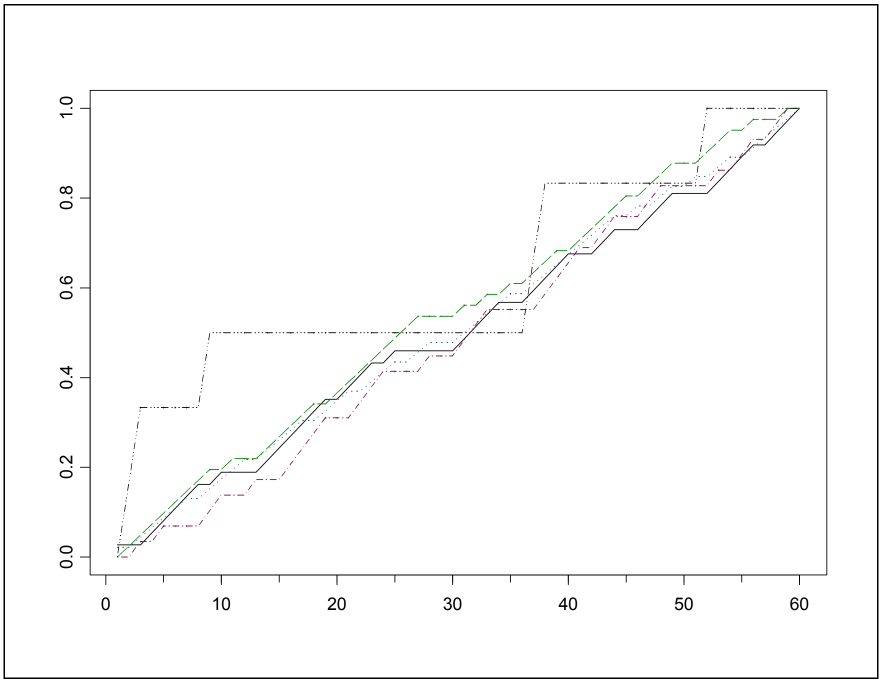
2 voices, non-spatialized, alpha



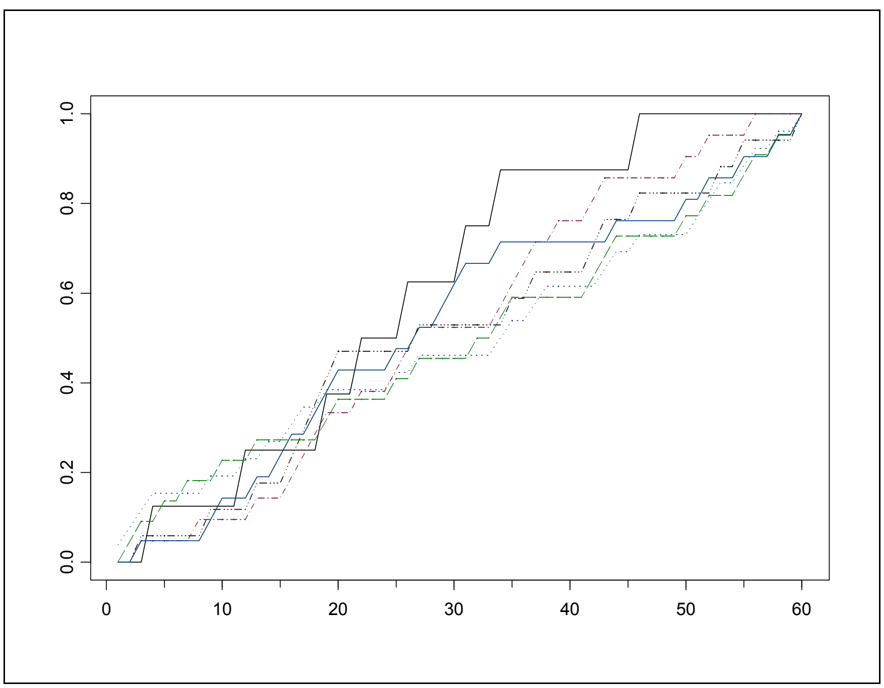
2 voices, spatialized, alpha



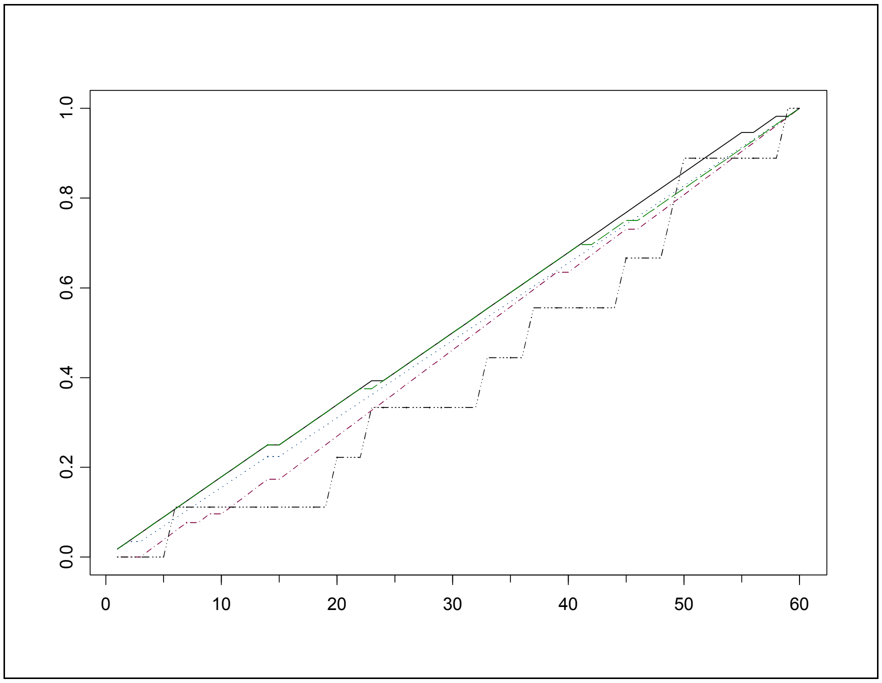
4 voices, spatialized, alpha



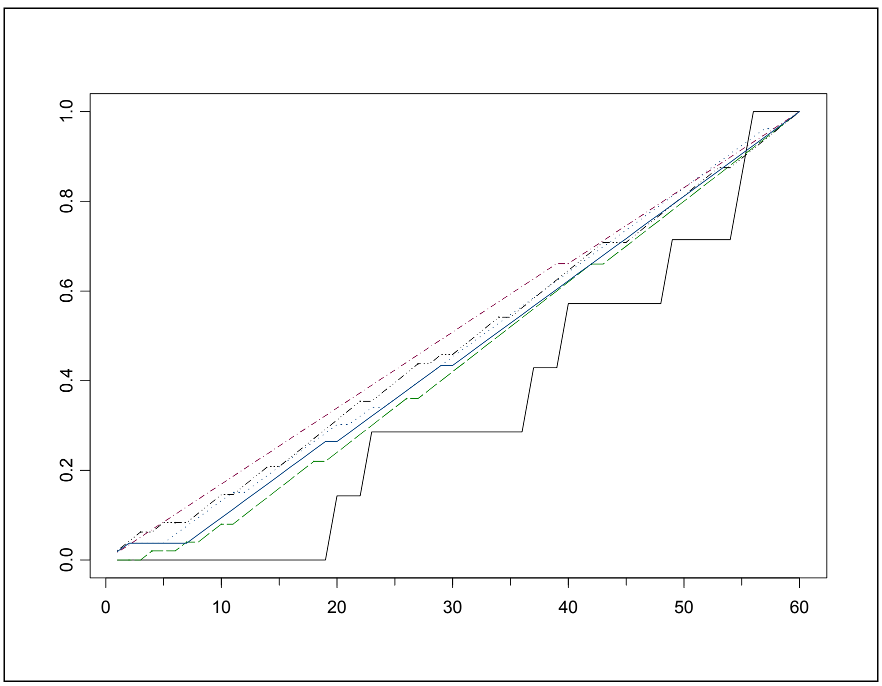
4 voices, non-spatialized, alpha



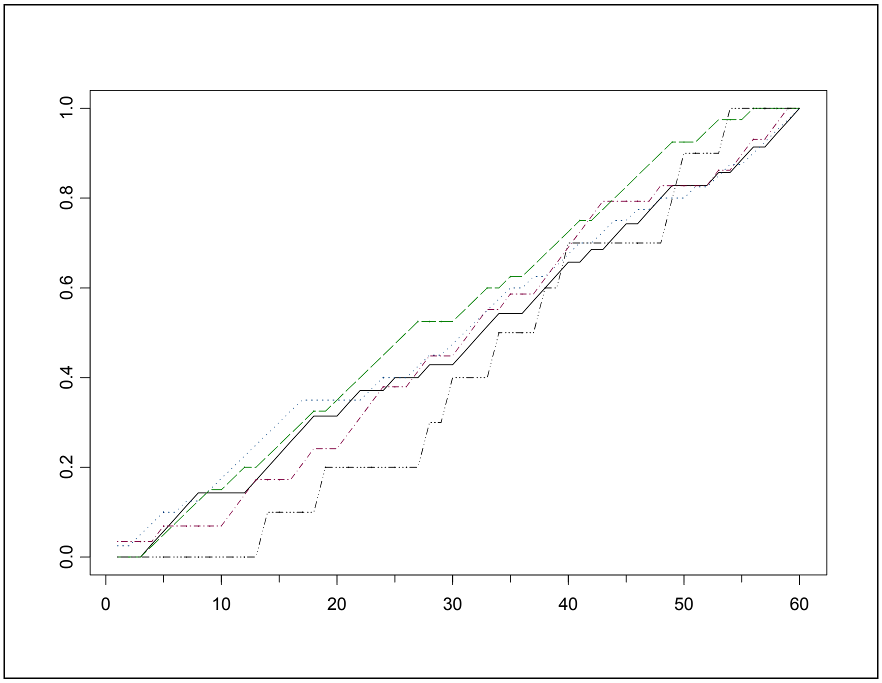
2 voices, spatialized, number



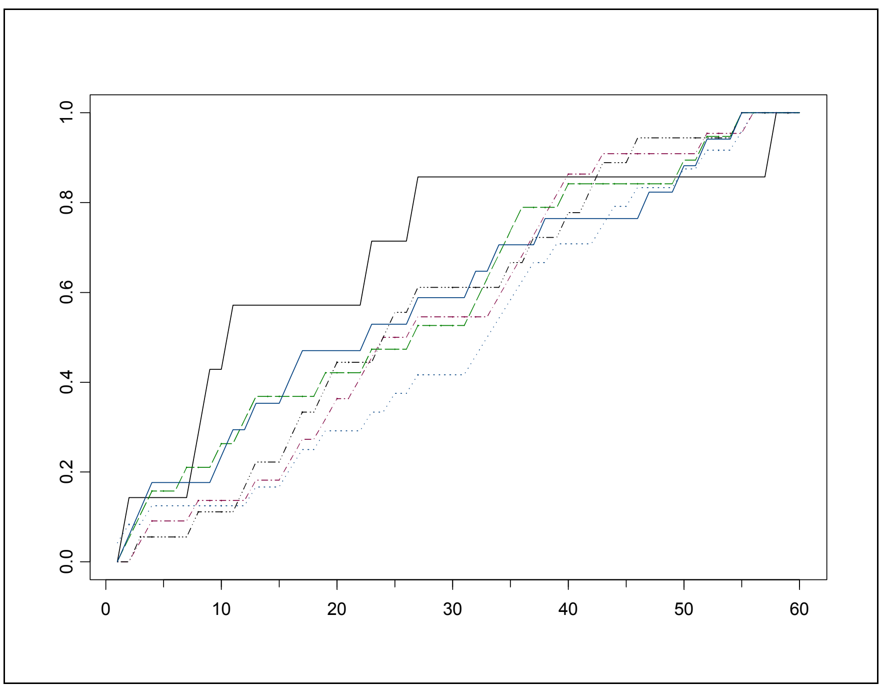
2 voices, non-spatialized, number



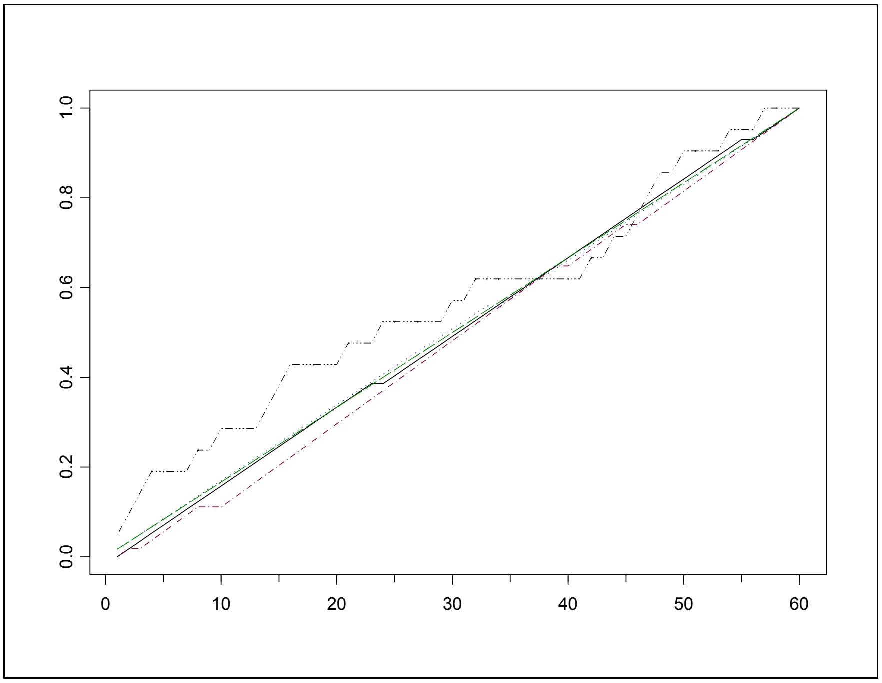
4 voices, spatialized, number



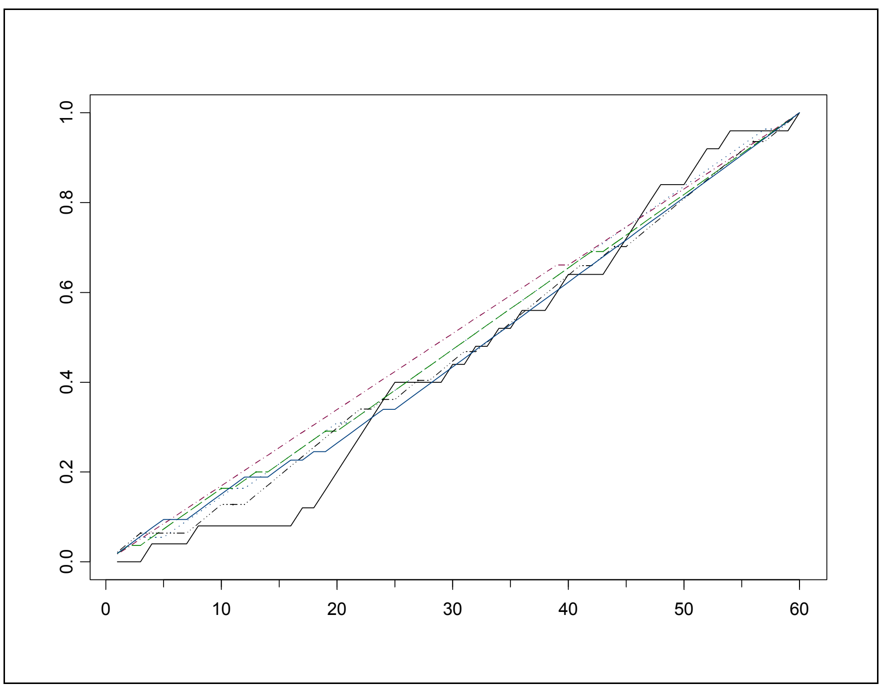
4 voices, non-spatialized, number



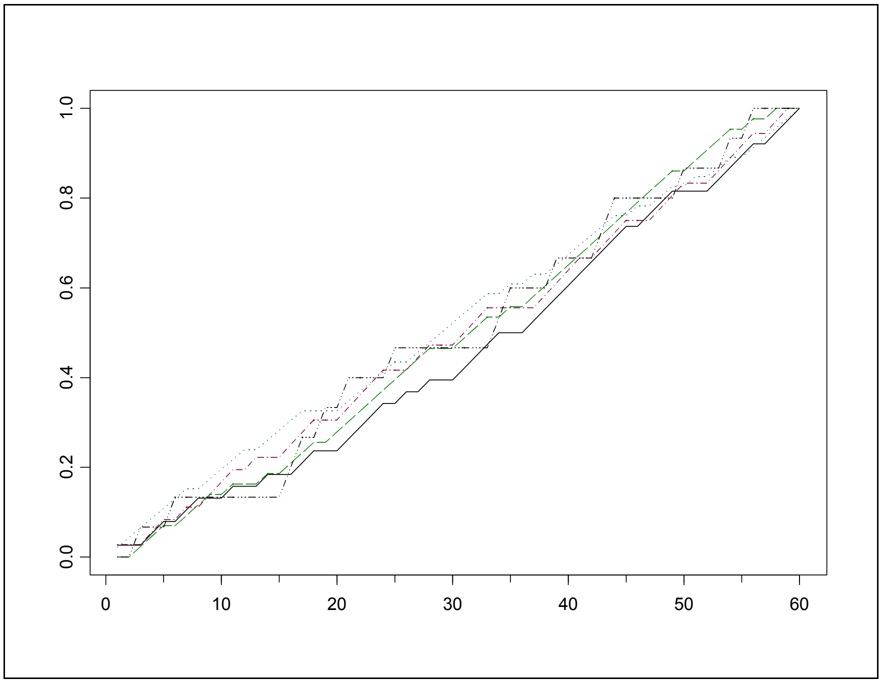
2 voices, spatialized, speaker



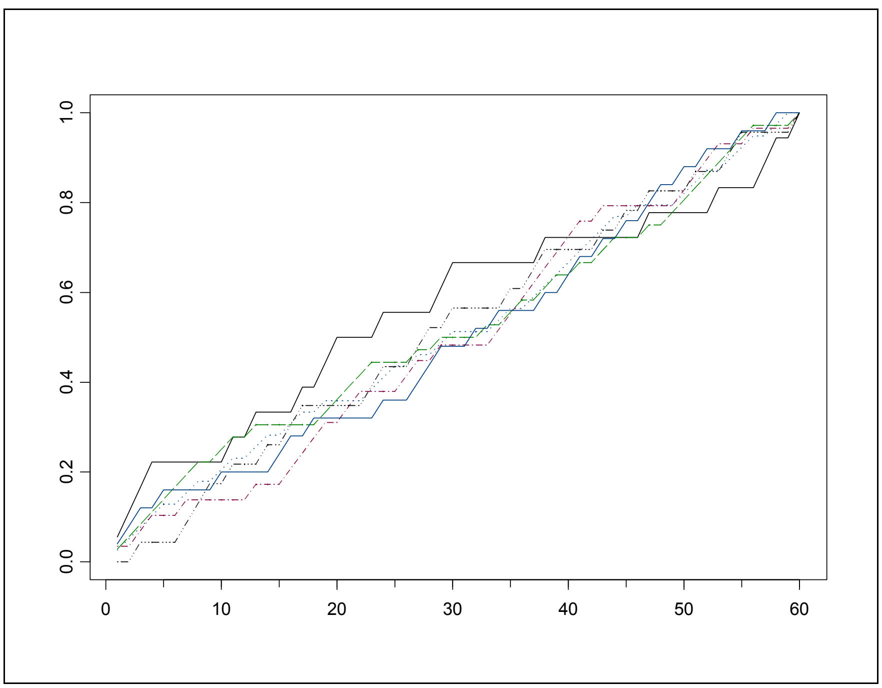
2 voices, non-spatialized, speaker



4 voices, spatialized, speaker



4 voices, non-spatialized, speaker



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APPENDIX F. FINAL EXPERIMENT SCRIPT GENERATOR

```
import java.util.*;

public class ScriptMaker2{

   public static void main(String args[]){

      //target messages for 3 and 4 source experiments

      ArrayList v41Target = new ArrayList();
      ArrayList v42Target = new ArrayList();
      ArrayList v43Target = new ArrayList();
      ArrayList v44Target = new ArrayList();

      //distractor messages for 3 and 4 source experiments

      ArrayList v41Distractors = new ArrayList();
      ArrayList v42Distractors = new ArrayList();
      ArrayList v43Distractors = new ArrayList();
      ArrayList v44Distractors = new ArrayList();

      ArrayList threeVoice = new ArrayList();
      ArrayList fourVoice = new ArrayList();
      Integer target = new Integer(0);
      int random;
      int index;

      ArrayList treatmentOne = new ArrayList();
      ArrayList treatmentTwo = new ArrayList();
      ArrayList temp = new ArrayList();
      ArrayList bin = new ArrayList();

      //fill two arrays with sequences of 0 and 1 with runs no larger than 6

      for (int j = 0; j<10 ;j++){
         for (int k=0;k<3;k++){
            bin.add(new Integer(0));
            bin.add(new Integer(1));
         }
         while (bin.size()>0){
            random = (int)(bin.size()*Math.random());
            target = (Integer)bin.remove(random);
            treatmentOne.add(target);
         }
      }
      for (int j = 0; j<10 ;j++){
         for (int k=0;k<3;k++){
            bin.add(new Integer(0));
            bin.add(new Integer(1));
         }
         while (bin.size()>0){
            random = (int)(bin.size()*Math.random());
            target = (Integer)bin.remove(random);
            treatmentTwo.add(target);
         }
      }

System.out.println(treatmentOne.size());
System.out.println(treatmentTwo.size());


      //populate arrays with message file identifiers
      for (int i=4101; i <= 4115; i++){
         v41Target.add(new Integer(i));
      }

      for (int i=4201; i <= 4215; i++){
```

```
   v42Target.add(new Integer(i));
}

for (int i=4301; i <= 4315; i++){
   v43Target.add(new Integer(i));
}

for (int i=4401; i <= 4415; i++){
   v44Target.add(new Integer(i));
}

for (int i=4116; i <= 4160; i++){
   v41Distractors.add(new Integer(i));
}

for (int i=4216; i <= 4260; i++){
   v42Distractors.add(new Integer(i));
}

for (int i=4316; i <= 4360; i++){
   v43Distractors.add(new Integer(i));
}

for (int i=4416; i <= 4460; i++){
   v44Distractors.add(new Integer(i));
}

//Experiment with three sources
for (int i =0; i<20; i++){
   threeVoice.add(new Integer(1));
   threeVoice.add(new Integer(2));
   threeVoice.add(new Integer(3));
}
System.out.println("Three Voice Trials");
while(threeVoice.size()>0){
   index = 60 - threeVoice.size();
   random = (int)(threeVoice.size()*Math.random());
   target = (Integer)threeVoice.remove(random);
   switch(target.intValue()){
      case 1:
         System.out.print(index + 1 + ":");
         System.out.print(((Integer)treatmentOne.remove(0)).intValue() +
           ":");
         random = (int)(v41Target.size()*Math.random());
         target = (Integer)v41Target.get(random);
         System.out.print(target.intValue()+":");
         random = (int)(v43Distractors.size()*Math.random());
         target = (Integer)v43Distractors.get(random);
         System.out.print(target.intValue()+":");
         random = (int)(v44Distractors.size()*Math.random());
         target = (Integer)v44Distractors.get(random);
         System.out.println(target.intValue());
         break;

      case 2:
         System.out.print(index + 1 + ":");
         System.out.print(((Integer)treatmentOne.remove(0)).intValue() +
           ":");
         random = (int)(v43Target.size()*Math.random());
         target = (Integer)v43Target.get(random);
         System.out.print(target.intValue()+":");
         random = (int)(v41Distractors.size()*Math.random());
         target = (Integer)v41Distractors.get(random);
         System.out.print(target.intValue()+":");
         random = (int)(v44Distractors.size()*Math.random());
         target = (Integer)v44Distractors.get(random);
         System.out.println(target.intValue());
         break;

      default:
         System.out.print(index + 1 + ":");
```

```
            System.out.print(((Integer)treatmentOne.remove(0)).intValue() +
              ":");
            random = (int)(v44Target.size()*Math.random());
            target = (Integer)v44Target.get(random);
            System.out.print(target.intValue()+":");
            random = (int)(v43Distractors.size()*Math.random());
            target = (Integer)v43Distractors.get(random);
            System.out.print(target.intValue()+":");
            random = (int)(v41Distractors.size()*Math.random());
            target = (Integer)v41Distractors.get(random);
            System.out.println(target.intValue());
            break;
    }
}

//Experiment with four sources
for (int i =0; i<15; i++){
    fourVoice.add(new Integer(1));
    fourVoice.add(new Integer(2));
    fourVoice.add(new Integer(3));
    fourVoice.add(new Integer(4));

}
System.out.println("Four Voice Trials");
while(fourVoice.size()>0){
    index = 60 - fourVoice.size();
    random = (int)(fourVoice.size()*Math.random());
    target = (Integer)fourVoice.remove(random);
    switch(target.intValue()){
        case 1:
            System.out.print(index + 1 + ":");
            System.out.print(((Integer)treatmentTwo.remove(0)).intValue() +
              ":");
            random = (int)(v41Target.size()*Math.random());
            target = (Integer)v41Target.remove(random);
            System.out.print(target.intValue()+":");
            random = (int)(v42Distractors.size()*Math.random());
            target = (Integer)v42Distractors.remove(random);
            System.out.print(target.intValue()+":");
            random = (int)(v43Distractors.size()*Math.random());
            target = (Integer)v43Distractors.remove(random);
            System.out.print(target.intValue()+":");
            random = (int)(v44Distractors.size()*Math.random());
            target = (Integer)v44Distractors.remove(random);
            System.out.println(target.intValue());
            break;

        case 2:
            System.out.print(index + 1 + ":");
            System.out.print(((Integer)treatmentTwo.remove(0)).intValue() +
              ":");
            random = (int)(v42Target.size()*Math.random());
            target = (Integer)v42Target.remove(random);
            System.out.print(target.intValue()+":");
            random = (int)(v41Distractors.size()*Math.random());
            target = (Integer)v41Distractors.remove(random);
            System.out.print(target.intValue()+":");
            random = (int)(v43Distractors.size()*Math.random());
            target = (Integer)v43Distractors.remove(random);
            System.out.print(target.intValue()+":");
            random = (int)(v44Distractors.size()*Math.random());
            target = (Integer)v44Distractors.remove(random);
            System.out.println(target.intValue());
            break;

        case 3:
            System.out.print(index + 1 + ":");
            System.out.print(((Integer)treatmentTwo.remove(0)).intValue() +
              ":");
            random = (int)(v43Target.size()*Math.random());
            target = (Integer)v43Target.remove(random);
```

```
                System.out.print(target.intValue()+":");
                random = (int)(v42Distractors.size()*Math.random());
                target = (Integer)v42Distractors.remove(random);
                System.out.print(target.intValue()+":");
                random = (int)(v41Distractors.size()*Math.random());
                target = (Integer)v41Distractors.remove(random);
                System.out.print(target.intValue()+":");
                random = (int)(v44Distractors.size()*Math.random());
                target = (Integer)v44Distractors.remove(random);
                System.out.println(target.intValue());
                break;

            default:
                System.out.print(index + 1 + ":");
                System.out.print(((Integer)treatmentTwo.remove(0)).intValue() +
                  ":");
                random = (int)(v44Target.size()*Math.random());
                target = (Integer)v44Target.remove(random);
                System.out.print(target.intValue()+":");
                random = (int)(v42Distractors.size()*Math.random());
                target = (Integer)v42Distractors.remove(random);
                System.out.print(target.intValue()+":");
                random = (int)(v43Distractors.size()*Math.random());
                target = (Integer)v43Distractors.remove(random);
                System.out.print(target.intValue()+":");
                random = (int)(v41Distractors.size()*Math.random());
                target = (Integer)v41Distractors.remove(random);
                System.out.println(target.intValue());
                break;
         }
      }
   }
}
```

APPENDIX G. FINAL EXPERIMENT SCRIPT

3 Voice Trials	Treatment	T	D1	D2
1	1	4401	4333	4144
2	1	4111	4346	4438
3	1	4310	4134	4447
4	0	4301	4159	4451
5	0	4305	4158	4452
6	0	4107	4320	4441
7	1	4409	4336	4146
8	0	4405	4358	4151
9	0	4308	4146	4445
10	1	4114	4337	4421
11	0	4308	4116	4446
12	1	4407	4336	4153
13	1	4410	4352	4149
14	0	4307	4152	4443
15	1	4308	4137	4447
16	0	4414	4349	4123
17	1	4314	4157	4432
18	0	4312	4124	4418
19	1	4314	4147	4440
20	1	4112	4329	4443
21	0	4411	4335	4120
22	0	4111	4327	4433
23	1	4401	4348	4128
24	0	4304	4131	4440
25	0	4103	4320	4422
26	1	4107	4322	4437
27	1	4309	4132	4441
28	0	4108	4330	4429
29	0	4302	4144	4416
30	1	4110	4335	4446
31	1	4405	4355	4144
32	1	4403	4339	4160
33	0	4105	4342	4452
34	0	4311	4144	4426
35	0	4314	4126	4430

36	1	4415	4335	4143
37	0	4308	4124	4417
38	0	4405	4342	4123
39	0	4108	4342	4439
40	1	4407	4337	4149
41	1	4109	4334	4416
42	1	4312	4139	4416
43	1	4308	4128	4449
44	1	4112	4331	4439
45	1	4410	4322	4143
46	0	4409	4316	4158
47	0	4401	4359	4129
48	0	4102	4348	4419
49	0	4403	4340	4156
50	1	4303	4131	4457
51	0	4112	4341	4430
52	1	4410	4345	4131
53	0	4111	4333	4457
54	1	4112	4324	4418
55	1	4115	4318	4438
56	0	4103	4327	4436
57	0	4304	4147	4428
58	1	4403	4333	4123
59	0	4102	4321	4448
60	1	4411	4320	4122

4 Voice Trials	Treatment	T	D1	D2	D3
1	1	4414	4234	4320	4125
2	1	4302	4235	4122	4447
3	1	4206	4150	4343	4459
4	0	4115	4220	4326	4444
5	0	4102	4225	4322	4458
6	0	4413	4240	4323	4160
7	1	4103	4251	4330	4433
8	0	4202	4133	4354	4454
9	1	4212	4126	4351	4442
10	1	4305	4238	4119	4450
11	0	4213	4146	4328	4428
12	0	4101	4247	4357	4422

13	0	4407	4243	4345	4116
14	0	4210	4118	4360	4455
15	1	4111	4248	4350	4436
16	1	4405	4233	4355	4139
17	1	4408	4221	4332	4137
18	0	4306	4218	4149	4453
19	1	4310	4219	4153	4446
20	0	4313	4260	4154	4441
21	0	4312	4246	4123	4457
22	0	4201	4132	4331	4420
23	1	4406	4227	4352	4130
24	1	4114	4228	4339	4456
25	1	4113	4256	4359	4434
26	0	4214	4131	4318	4440
27	0	4215	4134	4338	4419
28	1	4304	4249	4157	4423
29	1	4108	4259	4340	4426
30	0	4411	4236	4348	4159
31	1	4104	4232	4342	4430
32	0	4204	4155	4358	4417
33	0	4209	4151	4329	4432
34	0	4105	4258	4347	4431
35	1	4410	4237	4341	4145
36	1	4308	4229	4147	4418
37	0	4314	4250	4135	4451
38	1	4307	4230	4144	4416
39	1	4106	4222	4346	4437
40	0	4208	4129	4335	4452
41	0	4401	4231	4319	4138
42	1	4403	4242	4353	4158
43	1	4412	4244	4356	4156
44	0	4110	4226	4325	4429
45	0	4207	4127	4316	4460
46	0	4107	4252	4334	4439
47	1	4404	4216	4349	4142
48	1	4415	4223	4327	4148
49	0	4112	4241	4317	4443
50	1	4309	4217	4140	4449
51	1	4311	4253	4152	4445

52	1	4211	4136	4321	4438
53	0	4109	4224	4337	4425
54	0	4409	4239	4333	4120
55	1	4402	4257	4324	4128
56	1	4203	4141	4344	4424
57	1	4205	4121	4336	4427
58	0	4303	4254	4124	4435
59	0	4301	4255	4117	4421
60	0	4315	4245	4143	4448

APPENDIX H. FINAL EXPERIMENT PROCEDURE CHECKLIST

1) Ask participant to be seated and complete consent forms.

2) Ask participants to place headphones over ears with red tape on the right.

3) Explain the structure of a message (addressee call sign, speaker call sign, two-part coordinate).

- Show the participant the list of call signs, coordinate system illustration, and sample message text.

- Tell the participant that they will be listening for messages addressed to Yankee One.

4) Demonstrate the use of the data input form.

5) Play example messages for each voice, one at a time. Identify them by call sign before playing them.

6) Explain the general structure of the experiment.

- 120 trials with overlapping messages. 60 with 3 voices, 60 with four.

- Some trials will be spatially separated (show diagrams on input form), others will not.

7) Play a three voice example message without separation, then with spatial separation.

8) Explain the purpose of the inertial head tracker and demonstrate its use with the message from part 7.

9) Conduct 10 practice sessions. (No data collected, both 3 and 4 voice)

10) Start experiment

- Experimenter loads trial and announces whether it will be spatialized or not.

- Participant listens, listens, responds and indicates that they are ready to proceed by reading the record number at the bottom of the screen.

- The experimenter loads the next trial.

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APPENDIX I. LOGIT REGRESSION OUTPUT

This appendix contains the S-plus output for each of the final logit regression models. Every model has a summary that shows coefficient estimates and an analysis of deviance. Highlighted elements show the response variable and data set that were used. The following key explains the abbreviations that were used:

Speak = correct speaker identification (binary variable)
Alpha = correct alphabetical coordinate identification (binary variable)
Num = correct numerical coordinate identification (binary variable)
Agg = correct coordinate (both parts) identification (binary variable)
f3vall = three voice data
f4vall = four voice data

```
       *** Generalized Linear Model ***

Call: glm(formula = Speak ~ Treat + Stage + Subject + Source, family =
binomial, data = f3vall)
Deviance Residuals:
       Min         1Q   Median      3Q     Max
 -2.569538 -0.7478461 0.351806 0.71016 2.67143

Coefficients:
                  Value Std. Error    t value
(Intercept)  0.51483913 0.06853504  7.5120572
      Treat  0.77602143 0.08376821  9.2639127
     Stage1 -0.28109560 0.16589010 -1.6944688
     Stage2  0.00736669 0.09225094  0.0798549
     Stage3  0.04824321 0.06760162  0.7136398
     Stage4  0.06979610 0.05241986  1.3314819
     Stage5 -0.02202121 0.04398261 -0.5006799
     Stage6  0.03470497 0.03443255  1.0079118
     Stage7  0.01055481 0.03043267  0.3468248
     Stage8 -0.10481898 0.02877001 -3.6433425
     Stage9  0.10565815 0.02641267  4.0002835
    Stage10  0.03500396 0.02428357  1.4414671
    Stage11  0.04980357 0.02002787  2.4867130
   Subject1 -0.98368493 0.21937383 -4.4840577
   Subject2  0.11370396 0.11880591  0.9570564
   Subject3 -0.24797918 0.09138307 -2.7136227
   Subject4  0.01447072 0.06503684  0.2225004
   Subject5  0.35984256 0.06198609  5.8052144
   Subject6  0.11819529 0.04530685  2.6087729
   Subject7  0.18206240 0.04348514  4.1867728
   Subject8  0.21013035 0.04426841  4.7467331
   Subject9  0.15409028 0.03829152  4.0241357
  Subject10 -0.12700250 0.02902638 -4.3754164
  Subject11  0.19844368 0.04097254  4.8433332
  Subject12 -0.13483421 0.02552822 -5.2817711
  Subject13  0.07735733 0.02485853  3.1119027
  Subject14 -0.12681104 0.02282596 -5.5555611
  Subject15  0.13436475 0.02853976  4.7079847
  Subject16  0.05871127 0.02035491  2.8843784
  Subject17  0.02414078 0.01750371  1.3791807
  Subject18 -0.12324252 0.01934308 -6.3713997
  Subject19  0.04122791 0.01648310  2.5012233
```

```
  Subject20 -0.09097889 0.01614731 -5.6343058
  Subject21  0.06024083 0.01649920  3.6511374
  Subject22  0.05500250 0.01576402  3.4891161
  Subject23 -0.05641701 0.01279552 -4.4091237
  Subject24  0.03680053 0.01337891  2.7506371
    Source1 -0.29099351 0.09156910 -3.1778571
    Source2 -0.52734197 0.05665785 -9.3074832

(Dispersion Parameter for Binomial family taken to be 1 )

    Null Deviance: 2034.146 on 1499 degrees of freedom

Residual Deviance: 1421.218 on 1461 degrees of freedom

Number of Fisher Scoring Iterations: 4
```

Analysis of Deviance Table

```
Binomial model

Response: Speak (3 voice)

Terms added sequentially (first to last)
        Df Deviance Resid. Df Resid. Dev     Pr(Chi)
   NULL                  1499   2034.146
  Treat  1  34.6370      1498   1999.509 0.000000004
  Stage 11  28.0974      1487   1971.412 0.003128002
Subject 24 444.8308      1463   1526.581 0.000000000
 Source  2 105.3630      1461   1421.218 0.000000000
```

***** Generalized Linear Model *****

```
Call: glm(formula = Alpha ~ Treat + Stage + Subject + Source, family =
binomial, data = f3vall)
Deviance Residuals:
       Min         1Q     Median        3Q      Max
 -2.566268 -0.6755575 -0.1975927 0.6615144 3.235951

Coefficients:
                   Value Std. Error     t value
(Intercept) -0.499155389 0.07653958  -6.5215328
      Treat  1.263212777 0.09485824  13.3168482
     Stage1 -0.259662770 0.17957489  -1.4459860
     Stage2  0.185103185 0.09944802   1.8613058
     Stage3  0.022434910 0.07309242   0.3069390
     Stage4  0.199496485 0.05607067   3.5579470
     Stage5 -0.005238942 0.04574889  -0.1145152
     Stage6  0.079603400 0.03643722   2.1846727
     Stage7  0.015658917 0.03275446   0.4780698
     Stage8 -0.097809063 0.02993390  -3.2675010
     Stage9  0.081708106 0.02761867   2.9584370
    Stage10 -0.004421301 0.02400394  -0.1841907
    Stage11  0.045472721 0.02048126   2.2202111
   Subject1 -1.037291766 0.24537299  -4.2274081
   Subject2  0.137001144 0.12994851   1.0542725
   Subject3 -0.423645895 0.12306863  -3.4423550
   Subject4  0.157889550 0.07069623   2.2333518
   Subject5  0.298009968 0.05735961   5.1954673
   Subject6  0.086177557 0.04715274   1.8276258
   Subject7  0.152941999 0.04087090   3.7420759
   Subject8  0.238028131 0.03989194   5.9668227
   Subject9  0.110452715 0.03248956   3.3996369
  Subject10 -0.177333609 0.03823750  -4.6376878
```

```
  Subject11  0.173727449 0.02999249   5.7923650
  Subject12 -0.239601886 0.04751546  -5.0426094
  Subject13  0.145498598 0.02521758   5.7697286
  Subject14 -0.179767694 0.03647320  -4.9287613
  Subject15  0.159908057 0.02409242   6.6372760
  Subject16  0.070852939 0.01891440   3.7459783
  Subject17  0.032845313 0.01728108   1.9006514
  Subject18 -0.093698742 0.02105425  -4.4503480
  Subject19  0.089592642 0.01710556   5.2376332
  Subject20 -0.147640655 0.02931237  -5.0368038
  Subject21 -0.025582336 0.01488134  -1.7190886
  Subject22  0.063845149 0.01408433   4.5330627
  Subject23 -0.083129859 0.01814655  -4.5810294
  Subject24  0.094421456 0.01480635   6.3770905
    Source1 -0.234314454 0.09405247  -2.4913164
    Source2 -0.425853223 0.06000716  -7.0967073

(Dispersion Parameter for Binomial family taken to be 1 )

    Null Deviance: 2058.269 on 1499 degrees of freedom

Residual Deviance: 1296.23 on 1461 degrees of freedom

Number of Fisher Scoring Iterations: 5
```

Analysis of Deviance Table

```
Binomial model

Response: Alpha (3 voice)

Terms added sequentially (first to last)
        Df Deviance Resid. Df Resid. Dev    Pr(Chi)
   NULL                  1499   2058.269
  Treat  1 126.9351      1498   1931.334 0.00000000
  Stage 11  20.4466      1487   1910.887 0.03957924
Subject 24 553.1791      1463   1357.708 0.00000000
 Source  2  61.4782      1461   1296.230 0.00000000
```

***** Generalized Linear Model *****

```
Call: glm(formula = Num ~ Treat + Stage + Subject + Source, family = binomial,
data = f3vall)
Deviance Residuals:
       Min         1Q     Median        3Q      Max
 -2.463239 -0.7144343 -0.1357621 0.7214571 3.106442

Coefficients:
                   Value Std. Error    t value
(Intercept) -0.403921255 0.08491128 -4.7569801
      Treat  0.853645614 0.08547409  9.9871859
     Stage1 -0.063945583 0.16861896 -0.3792313
     Stage2  0.179921915 0.09533913  1.8871780
     Stage3  0.166318809 0.06974348  2.3847220
     Stage4  0.165916765 0.05409936  3.0668898
     Stage5  0.025520030 0.04465662  0.5714724
     Stage6  0.018728751 0.03515622  0.5327294
     Stage7  0.016523652 0.03134518  0.5271513
     Stage8 -0.051432799 0.02955989 -1.7399522
     Stage9  0.028128683 0.02641854  1.0647328
    Stage10  0.006522976 0.02348092  0.2777990
    Stage11  0.048732661 0.02023034  2.4088894
   Subject1 -1.239805442 0.26351171 -4.7049349
```

```
   Subject2  0.171939992 0.13075991  1.3149289
   Subject3 -0.228341997 0.10696289 -2.1347777
   Subject4  0.180295788 0.06692436  2.6940231
   Subject5  0.350952206 0.05699136  6.1579901
   Subject6  0.075618570 0.04468605  1.6922188
   Subject7  0.155877638 0.03922647  3.9737875
   Subject8  0.250966248 0.04154623  6.0406503
   Subject9  0.118192947 0.03188838  3.7064577
  Subject10 -0.193685485 0.03919961 -4.9410051
  Subject11  0.173601877 0.03078794  5.6386331
  Subject12 -0.325374834 0.07468093 -4.3568663
  Subject13  0.127722354 0.02434595  5.2461448
  Subject14 -0.268814691 0.06481189 -4.1476137
  Subject15  0.133828285 0.02230624  5.9995899
  Subject16  0.068102263 0.01836822  3.7076130
  Subject17  0.051377075 0.01700326  3.0216012
  Subject18 -0.076138022 0.01998416 -3.8099192
  Subject19  0.087601785 0.01679838  5.2148951
  Subject20 -0.109815382 0.02340915 -4.6911310
  Subject21  0.004598651 0.01359604  0.3382347
  Subject22  0.068438750 0.01401183  4.8843546
  Subject23 -0.064932167 0.01623844 -3.9986707
  Subject24  0.088521063 0.01463806  6.0473202
    Source1  0.020954176 0.09161779  0.2287130
    Source2 -0.370769939 0.05640229 -6.5736684

(Dispersion Parameter for Binomial family taken to be 1 )

    Null Deviance: 2071.945 on 1499 degrees of freedom

Residual Deviance: 1363.367 on 1461 degrees of freedom

Number of Fisher Scoring Iterations: 5
```

Analysis of Deviance Table

```
Binomial model

Response: Num (3 voice)

Terms added sequentially (first to last)
        Df Deviance Resid. Df Resid. Dev    Pr(Chi)
   NULL                  1499   2071.945
  Treat  1  59.9078      1498   2012.037 0.00000000
  Stage 11  19.3649      1487   1992.672 0.05485044
Subject 24 583.7778      1463   1408.894 0.00000000
 Source  2  45.5271      1461   1363.367 0.00000000
```

***** Generalized Linear Model *****

```
Call: glm(formula = Agg ~ Treat + Stage + Subject + Source, family = binomial,
data = f3vall)
Deviance Residuals:
       Min         1Q      Median        3Q      Max
 -2.583374 -0.5161874 -0.09603849 0.5794216 3.954573

Coefficients:
                   Value Std. Error     t value
(Intercept) -1.337509044 0.20599836  -6.4928140
      Treat  1.368148809 0.10459559  13.0803677
     Stage1 -0.055561464 0.19424669  -0.2860356
     Stage2  0.211627723 0.10700333   1.9777677
```

```
      Stage3  0.051685412 0.08156082   0.6337039
      Stage4  0.246444043 0.06048497   4.0744673
      Stage5  0.006673028 0.05060675   0.1318604
      Stage6  0.046956481 0.03860380   1.2163693
      Stage7  0.064338551 0.03496131   1.8402785
      Stage8 -0.100855992 0.03266206  -3.0878639
      Stage9  0.095760408 0.03054226   3.1353416
     Stage10  0.008644336 0.02630459   0.3286246
     Stage11  0.046346353 0.02181777   2.1242481
    Subject1 -1.735116314 0.39966388  -4.3414389
    Subject2  0.417885929 0.16973539   2.4619847
    Subject3 -0.721547551 0.26503305  -2.7224814
    Subject4  0.350868033 0.09138266   3.8395471
    Subject5  0.433507989 0.06891996   6.2900206
    Subject6  0.138566306 0.05562214   2.4912077
    Subject7  0.253621705 0.04621862   5.4874360
    Subject8  0.294892981 0.04238476   6.9575247
    Subject9  0.129753500 0.03462833   3.7470334
   Subject10 -0.342350288 0.09398121  -3.6427525
   Subject11  0.232658080 0.03196711   7.2780462
   Subject12 -0.587069736 0.33449107  -1.7551133
   Subject13  0.216747491 0.03551718   6.1026092
   Subject14 -0.219055914 0.07179255  -3.0512346
   Subject15  0.211586804 0.03024594   6.9955440
   Subject16  0.124581754 0.02557960   4.8703551
   Subject17  0.074949824 0.02313327   3.2399153
   Subject18 -0.144458591 0.04139968  -3.4893650
   Subject19  0.127826209 0.02090685   6.1140816
   Subject20 -0.164822324 0.05009207  -3.2903877
   Subject21  0.005143384 0.01856959   0.2769788
   Subject22  0.095219409 0.01691461   5.6294190
   Subject23 -0.092411779 0.02720949  -3.3963073
   Subject24  0.121078751 0.01643286   7.3680884
     Source1 -0.182911127 0.10188991  -1.7951840
     Source2 -0.477302144 0.06588310  -7.2446829

(Dispersion Parameter for Binomial family taken to be 1 )

    Null Deviance: 2005.347 on 1499 degrees of freedom

Residual Deviance: 1107.34 on 1461 degrees of freedom

Number of Fisher Scoring Iterations: 7
```

Analysis of Deviance Table

```
Binomial model

Response: Agg (3 voice)

Terms added sequentially (first to last)
        Df Deviance Resid. Df Resid. Dev    Pr(Chi)
   NULL                  1499   2005.347
  Treat  1 113.9209      1498   1891.426 0.00000000
  Stage 11  17.7211      1487   1873.705 0.08828136
Subject 24 704.3137      1463   1169.391 0.00000000
 Source  2  62.0513      1461   1107.340 0.00000000
```

***** Generalized Linear Model *****

```
Call: glm(formula = Total ~ Treat + Stage + Subject + Source, family =
binomial, data = f3vall)
Deviance Residuals:
```

```
       Min       1Q       Median        3Q      Max
 -2.552273 -0.49411 -0.008970102 0.5480952 3.548353

Coefficients:
                   Value Std. Error      t value
(Intercept) -2.578798794 1.05124187  -2.45309748
      Treat  1.449144223 0.11015470  13.15553693
     Stage1  0.007968436 0.20181965   0.03948295
     Stage2  0.234342267 0.10996509   2.13106058
     Stage3  0.045824336 0.08607050   0.53240464
     Stage4  0.246457805 0.06205051   3.97188992
     Stage5  0.031543198 0.05311618   0.59385287
     Stage6  0.059956522 0.03929985   1.52561710
     Stage7  0.058702616 0.03572191   1.64332256
     Stage8 -0.088977696 0.03378668  -2.63351401
     Stage9  0.125969527 0.03252690   3.87277955
    Stage10  0.001552376 0.02715262   0.05717222
    Stage11  0.059785057 0.02229459   2.68159479
   Subject1 -5.028818120 5.85566746  -0.85879503
   Subject2  1.505176148 1.95493803   0.76993548
   Subject3 -1.633498567 3.08526961  -0.52945083
   Subject4  1.011640367 0.83056404   1.21801609
   Subject5  0.848717648 0.55465420   1.53017438
   Subject6  0.442476101 0.39710396   1.11425758
   Subject7  0.486893906 0.29848257   1.63123063
   Subject8  0.466009276 0.23313753   1.99885998
   Subject9  0.284820896 0.18676361   1.52503421
  Subject10 -0.767368536 1.07490029  -0.71389741
  Subject11  0.387632845 0.15654385   2.47619344
  Subject12 -0.620101400 0.90989645  -0.68150766
  Subject13  0.332665060 0.13102926   2.53886078
  Subject14 -0.120540370 0.13087227  -0.92105357
  Subject15  0.307232697 0.10040632   3.05989398
  Subject16  0.207103261 0.08824325   2.34695862
  Subject17  0.147197741 0.07855167   1.87389693
  Subject18 -0.123636783 0.08730639  -1.41612518
  Subject19  0.179480634 0.06391869   2.80795213
  Subject20 -0.398605669 0.56027865  -0.71144184
  Subject21  0.066469947 0.05880971   1.13025461
  Subject22  0.153958515 0.05370186   2.86691217
  Subject23 -0.092781897 0.06393137  -1.45127346
  Subject24  0.151381891 0.04572986   3.31035125
    Source1 -0.232218954 0.10553896  -2.20031501
    Source2 -0.526318062 0.06949406  -7.57356916

(Dispersion Parameter for Binomial family taken to be 1 )

    Null Deviance: 1980.035 on 1499 degrees of freedom

Residual Deviance: 1030.291 on 1461 degrees of freedom

Number of Fisher Scoring Iterations: 9
```

Analysis of Deviance Table

```
Binomial model

Response: Total

Terms added sequentially (first to last)
        Df Deviance Resid. Df Resid. Dev    Pr(Chi)
   NULL                  1499   1980.035
  Treat  1 118.4673      1498   1861.567 0.00000000
```

```
  Stage 11  19.7659      1487   1841.801 0.04865615
Subject 24 739.9690      1463   1101.832 0.00000000
 Source  2  71.5412      1461   1030.291 0.00000000


*** Generalized Linear Model ***

Call: glm(formula = Speak ~ Treat + Stage + Subject + Source, family =
binomial, data = f4vall)
Deviance Residuals:
       Min          1Q     Median         3Q      Max
 -2.174215 -0.8338993 -0.4509354 0.8719862 2.588626

Coefficients:
                   Value Std. Error     t value
(Intercept) -0.451522032 0.06334102  -7.1284298
      Treat  0.596539304 0.06759594   8.8250765
     Stage1  0.046790786 0.15254361   0.3067371
     Stage2  0.103198411 0.09666732   1.0675625
     Stage3  0.044980362 0.06383973   0.7045826
     Stage4 -0.052857045 0.05156064  -1.0251433
     Stage5  0.024816547 0.04285539   0.5790765
     Stage6 -0.025831559 0.03594567  -0.7186279
     Stage7  0.039225145 0.03046676   1.2874735
     Stage8  0.068557955 0.02600499   2.6363387
     Stage9  0.019916461 0.02139056   0.9310863
    Stage10  0.020687407 0.01951456   1.0601010
    Stage11  0.043170842 0.01845950   2.3386787
   Subject1 -0.705798767 0.23217582  -3.0399322
   Subject2  0.116324956 0.12713202   0.9149934
   Subject3 -0.238291108 0.10287505  -2.3163159
   Subject4  0.017581331 0.07155458   0.2457052
   Subject5  0.135030598 0.05506644   2.4521396
   Subject6  0.032236297 0.04759825   0.6772580
   Subject7  0.166110976 0.03989017   4.1642080
   Subject8  0.100677833 0.03484805   2.8890520
   Subject9  0.011037067 0.03183511   0.3466948
  Subject10 -0.016267702 0.02951022  -0.5512565
  Subject11  0.125676961 0.02651850   4.7392183
  Subject12 -0.079369155 0.02770400  -2.8648992
  Subject13  0.060689982 0.02183315   2.7797173
  Subject14 -0.052107516 0.02293140  -2.2723221
  Subject15  0.047235189 0.01897828   2.4889074
  Subject16  0.026596324 0.01785580   1.4895060
  Subject17  0.056943676 0.01694425   3.3606492
  Subject18 -0.023422260 0.01691734  -1.3845121
  Subject19  0.067294017 0.01558715   4.3172748
  Subject20 -0.014175124 0.01493859  -0.9488929
  Subject21  0.038725797 0.01371860   2.8228674
  Subject22  0.031625403 0.01306585   2.4204634
  Subject23 -0.044732428 0.01445799  -3.0939583
  Subject24  0.009085493 0.01203031   0.7552171
    Source1 -1.237949591 0.10004557 -12.3738566
    Source2 -0.161965178 0.05603400  -2.8904806
    Source3 -0.249152959 0.04042451  -6.1634130

(Dispersion Parameter for Binomial family taken to be 1 )

    Null Deviance: 2036.904 on 1499 degrees of freedom

Residual Deviance: 1584.855 on 1460 degrees of freedom

Number of Fisher Scoring Iterations: 4
```

Analysis of Deviance Table

```
Binomial model

Response: Speak (4 voice)

Terms added sequentially (first to last)
        Df Deviance Resid. Df Resid. Dev   Pr(Chi)
   NULL                  1499   2036.904
  Treat  1  60.5642      1498   1976.340 0.0000000
  Stage 11  13.1459      1487   1963.194 0.2838985
Subject 24 129.6921      1463   1833.502 0.0000000
 Source  3 248.6474      1460   1584.855 0.0000000
```

***** Generalized Linear Model *****

```
Call: glm(formula = Alpha ~ Treat + Stage + Subject + Source, family =
binomial, data = f4vall)
Deviance Residuals:
       Min         1Q     Median        3Q      Max
 -2.415434 -0.6853618 -0.3211171 0.6586104 3.186737

Coefficients:
                  Value Std. Error     t value
(Intercept) -1.21083479 0.08412740 -14.3928706
      Treat  0.87971146 0.07952530  11.0620324
     Stage1  0.53821021 0.16575572   3.2470084
     Stage2  0.18178974 0.10034706   1.8116100
     Stage3 -0.08530765 0.07655722  -1.1142992
     Stage4 -0.03691810 0.05654307  -0.6529199
     Stage5 -0.03093163 0.04749748  -0.6512268
     Stage6 -0.01614141 0.03770636  -0.4280820
     Stage7  0.01028119 0.03408855   0.3016025
     Stage8  0.00436431 0.02953251   0.1477799
     Stage9  0.03251150 0.02334651   1.3925633
    Stage10  0.02637611 0.02161193   1.2204422
    Stage11  0.03582885 0.02248443   1.5934961
   Subject1 -1.25335229 0.28290880  -4.4302343
   Subject2 -0.03249213 0.15184138  -0.2139873
   Subject3 -0.20486068 0.12008960  -1.7058986
   Subject4  0.18498413 0.07479669   2.4731594
   Subject5  0.12332275 0.05997757   2.0561477
   Subject6  0.02754282 0.05268427   0.5227901
   Subject7  0.15556211 0.04139049   3.7584019
   Subject8  0.17962521 0.03613366   4.9711325
   Subject9  0.09093095 0.03219855   2.8240701
  Subject10 -0.16163340 0.04447131  -3.6345545
  Subject11  0.16275259 0.02711363   6.0026123
  Subject12 -0.23967573 0.05785558  -4.1426557
  Subject13  0.08184291 0.02279492   3.5904021
  Subject14 -0.14294851 0.03794390  -3.7673652
  Subject15  0.07543165 0.01983208   3.8035173
  Subject16  0.03427347 0.01915100   1.7896441
  Subject17  0.07560662 0.01740287   4.3444904
  Subject18 -0.13338521 0.03349237  -3.9825555
  Subject19  0.10195666 0.01603721   6.3575055
  Subject20 -0.05860815 0.02077423  -2.8211943
  Subject21  0.01669726 0.01493071   1.1183164
  Subject22  0.05144368 0.01349886   3.8109642
```

```
  Subject23 -0.07843082 0.02158876  -3.6329479
  Subject24  0.03411228 0.01255355   2.7173411
    Source1 -0.86024001 0.10481379  -8.2073170
    Source2 -0.47311406 0.06580858  -7.1892462
    Source3 -0.26688955 0.04617661  -5.7797557

(Dispersion Parameter for Binomial family taken to be 1 )

    Null Deviance: 1885.103 on 1499 degrees of freedom

Residual Deviance: 1298.966 on 1460 degrees of freedom

Number of Fisher Scoring Iterations: 5
```

Analysis of Deviance Table

```
Binomial model

Response: Alpha (4 voice)

Terms added sequentially (first to last)
        Df Deviance Resid. Df Resid. Dev      Pr(Chi)
   NULL                  1499   1885.103
  Treat  1  86.4979      1498   1798.606 0.0000000000
  Stage 11  32.4806      1487   1766.125 0.0006383718
Subject 24 290.4680      1463   1475.657 0.0000000000
 Source  3 176.6913      1460   1298.966 0.0000000000
```

***** Generalized Linear Model *****

```
Call: glm(formula = Num ~ Treat + Stage + Subject + Source, family = binomial,
data = f4vall)
Deviance Residuals:
       Min         1Q     Median        3Q      Max
 -2.361954 -0.7654238 -0.4178939 0.7764193 3.352208

Coefficients:
                   Value Std. Error       t value
(Intercept) -1.107489943 0.07979440 -13.879293327
      Treat  0.708496142 0.07329501   9.666362160
     Stage1  0.087651931 0.15777088   0.555564712
     Stage2  0.098181454 0.09619160   1.020686409
     Stage3 -0.029590594 0.07280296  -0.406447685
     Stage4 -0.039036937 0.05297006  -0.736962262
     Stage5  0.009934514 0.04357384   0.227992624
     Stage6 -0.034914637 0.03634385  -0.960675243
     Stage7  0.066620013 0.03111047   2.141401676
     Stage8  0.039036365 0.02776794   1.405807256
     Stage9 -0.006851529 0.02303643  -0.297421465
    Stage10  0.018561154 0.02091184   0.887590672
    Stage11  0.017340581 0.02118342   0.818592170
   Subject1 -1.085401763 0.25874217  -4.194916400
   Subject2 -0.001166630 0.13860607  -0.008416878
   Subject3 -0.319744911 0.12487995  -2.560418243
   Subject4  0.104539952 0.07359576   1.420461561
   Subject5  0.085943817 0.05852213   1.468569619
   Subject6  0.033064399 0.05032315   0.657041542
   Subject7  0.127185625 0.03991255   3.186607311
   Subject8  0.144361680 0.03455089   4.178233437
   Subject9  0.082897391 0.03095775   2.677759083
  Subject10 -0.122043917 0.04019992  -3.035923999
  Subject11  0.147122152 0.02585674   5.689895016
  Subject12 -0.105197025 0.03387973  -3.105014065
```

```
  Subject13  0.064888516 0.02162705   3.000341119
  Subject14 -0.101466488 0.03105635  -3.267173324
  Subject15  0.079339876 0.01873632   4.234549372
  Subject16  0.020968578 0.01829584   1.146084246
  Subject17  0.078452384 0.01662924   4.717736035
  Subject18 -0.189062540 0.05116179  -3.695385686
  Subject19  0.084352635 0.01522373   5.540863302
  Subject20 -0.053616244 0.01985526  -2.700354340
  Subject21  0.014787695 0.01427340   1.036031406
  Subject22  0.043105199 0.01296045   3.325902743
  Subject23 -0.034453703 0.01597236  -2.157083229
  Subject24  0.012075604 0.01248277   0.967381458
    Source1 -0.625502077 0.09634615  -6.492237181
    Source2 -0.354759491 0.06109698  -5.806498392
    Source3 -0.285285899 0.04525864  -6.303456859

(Dispersion Parameter for Binomial family taken to be 1 )

    Null Deviance: 1880.608 on 1499 degrees of freedom

Residual Deviance: 1424.494 on 1460 degrees of freedom

Number of Fisher Scoring Iterations: 5
```

Analysis of Deviance Table

```
Binomial model

Response: Num (4 voice)

Terms added sequentially (first to last)
        Df Deviance Resid. Df Resid. Dev   Pr(Chi)
   NULL                  1499   1880.608
  Treat  1  64.2700      1498   1816.338 0.0000000
  Stage 11  16.1308      1487   1800.208 0.1363446
Subject 24 242.0624      1463   1558.145 0.0000000
 Source  3 133.6512      1460   1424.494 0.0000000
```

***** Generalized Linear Model *****

```
Call: glm(formula = Agg ~ Treat + Stage + Subject + Source, family = binomial,
data = f4vall)
Deviance Residuals:
       Min        1Q     Median        3Q      Max
 -2.724998 -0.556848 -0.1961331 0.2451993 3.608104

Coefficients:
                   Value Std. Error      t value
(Intercept) -2.484958595 0.40716860  -6.10302122
      Treat  1.171229710 0.09677191  12.10299242
     Stage1  0.373484407 0.18547321   2.01368389
     Stage2  0.168745928 0.11816900   1.42800498
     Stage3 -0.030587399 0.08531868  -0.35850765
     Stage4 -0.038330297 0.06689854  -0.57296164
     Stage5 -0.001666578 0.05576482  -0.02988584
     Stage6 -0.073917176 0.04541962  -1.62742844
     Stage7  0.045707970 0.03867629   1.18180846
     Stage8  0.021721850 0.03295997   0.65903740
     Stage9 -0.002905869 0.02549042  -0.11399844
    Stage10  0.024988119 0.02363664   1.05717714
    Stage11  0.026313433 0.02681421   0.98132411
   Subject1 -1.483615609 0.36838841  -4.02731343
   Subject2  0.197758670 0.17731542   1.11529313
```

```
   Subject3 -0.737225357 0.27012335  -2.72921744
   Subject4  0.334657232 0.09735634   3.43744667
   Subject5  0.262617625 0.07323822   3.58580027
   Subject6  0.117010365 0.06243207   1.87420287
   Subject7  0.229125316 0.04799032   4.77440693
   Subject8  0.200191471 0.04101733   4.88065571
   Subject9  0.076676097 0.03796120   2.01985432
  Subject10 -0.311995834 0.09623291  -3.24209090
  Subject11  0.201328296 0.03019758   6.66703432
  Subject12 -0.635459279 0.52967842  -1.19970771
  Subject13  0.162213035 0.04537294   3.57510517
  Subject14 -0.138040192 0.06159412  -2.24112625
  Subject15  0.140425603 0.03599206   3.90157184
  Subject16  0.094158369 0.03275058   2.87501403
  Subject17  0.122586832 0.02939736   4.16999447
  Subject18 -0.421413421 0.36292755  -1.16115027
  Subject19  0.144507016 0.03071246   4.70515986
  Subject20 -0.054798911 0.03649952  -1.50135970
  Subject21  0.027679685 0.02788716   0.99256010
  Subject22  0.095376716 0.02412245   3.95385705
  Subject23 -0.119105087 0.04720699  -2.52303898
  Subject24  0.055304882 0.02159563   2.56092925
    Source1 -1.026235146 0.12391973  -8.28145064
    Source2 -0.548370288 0.07550067  -7.26311827
    Source3 -0.319874612 0.05394976  -5.92912039

(Dispersion Parameter for Binomial family taken to be 1 )

    Null Deviance: 1697.903 on 1499 degrees of freedom

Residual Deviance: 1027.397 on 1460 degrees of freedom

Number of Fisher Scoring Iterations: 8
```

Analysis of Deviance Table

```
Binomial model

Response: Agg (4 voice)

Terms added sequentially (first to last)
        Df Deviance Resid. Df Resid. Dev    Pr(Chi)
   NULL                  1499   1697.903
  Treat  1 117.8323      1498   1580.071 0.00000000
  Stage 11  19.8053      1487   1560.265 0.04808285
Subject 24 341.1622      1463   1219.103 0.00000000
 Source  3 191.7060      1460   1027.397 0.00000000
```

***** Generalized Linear Model *****

```
Call: glm(formula = Total ~ Treat + Stage + Subject + Source, family =
binomial, data = f4vall)
Deviance Residuals:
       Min         1Q     Median           3Q      Max
 -3.077598 -0.4361802 -0.1159388 -0.001087361 3.935196

Coefficients:
                   Value Std. Error      t value
(Intercept) -3.819044962 0.98159357  -3.89065808
      Treat  1.640541996 0.12773694  12.84312924
     Stage1 -0.096984735 0.20823264  -0.46575183
     Stage2  0.329837526 0.14176421   2.32666295
     Stage3  0.009840141 0.09414000   0.10452667
```

```
      Stage4 -0.090205199 0.08126436  -1.11002164
      Stage5  0.006028347 0.06814331   0.08846572
      Stage6 -0.016924547 0.05120087  -0.33055193
      Stage7  0.064291724 0.04424727   1.45300990
      Stage8  0.047293715 0.03650413   1.29557162
      Stage9  0.012025645 0.02683522   0.44812915
     Stage10  0.016648898 0.02536911   0.65626651
     Stage11  0.030825472 0.03115532   0.98941276
    Subject1 -4.893133244 5.43769170  -0.89985485
    Subject2  1.576213233 1.81772560   0.86713486
    Subject3 -1.617336619 2.86410503  -0.56469180
    Subject4  0.986851326 0.77328548   1.27617983
    Subject5  0.708106016 0.51684419   1.37005702
    Subject6  0.484862519 0.37067579   1.30805013
    Subject7  0.520985283 0.27833078   1.87182062
    Subject8  0.392571516 0.21729892   1.80659671
    Subject9  0.228165181 0.17512215   1.30289160
   Subject10 -0.207372316 0.17053132  -1.21603657
   Subject11  0.335617734 0.12071868   2.78016400
   Subject12 -0.638599778 0.84180487  -0.75860784
   Subject13  0.260678437 0.10668831   2.44336455
   Subject14 -0.080911141 0.10457739  -0.77369632
   Subject15  0.216858177 0.08171355   2.65388278
   Subject16  0.164389644 0.07250809   2.26719048
   Subject17  0.158985900 0.06472364   2.45638056
   Subject18 -0.441220966 0.57464168  -0.76781929
   Subject19  0.202580740 0.06011713   3.36976739
   Subject20 -0.042987825 0.06138225  -0.70032991
   Subject21  0.061099965 0.05109311   1.19585527
   Subject22  0.132045292 0.04569332   2.88981597
   Subject23 -0.345613148 0.45453504  -0.76036634
   Subject24  0.091117437 0.04331215   2.10373853
     Source1 -1.335980784 0.15037519  -8.88431634
     Source2 -0.612389828 0.08689292  -7.04763771
     Source3 -0.423900862 0.06317990  -6.70942577

(Dispersion Parameter for Binomial family taken to be 1 )

    Null Deviance: 1612.981 on 1499 degrees of freedom

Residual Deviance: 844.5036 on 1460 degrees of freedom

Number of Fisher Scoring Iterations: 9
```

Analysis of Deviance Table

```
Binomial model

Response: Total

Terms added sequentially (first to last)
        Df Deviance Resid. Df Resid. Dev    Pr(Chi)
   NULL                  1499   1612.981
  Treat  1 157.4023      1498   1455.578 0.00000000
  Stage 11  20.1265      1487   1435.452 0.04363533
Subject 24 357.3420      1463   1078.110 0.00000000
 Source  3 233.6063      1460    844.504 0.00000000
```

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